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ORIGINAL ARTICLES

STUDIES IN THE PERIODIC PARTIAL FAILURES OF THE PUNJAB-AMERICAN COTTONS IN THE PUNJAB

XIII. MANURING OF COTTON*

By R. H. Dastur† and Sucha Singh, Punjab Agricultural College, Lyallpur

(Received for publication on 23 November 1943)

(With Plate XI)

Manuring of cotton as of other crops is one of the basic problems in agriculture and forms an important part in any programme for crop improvement. Previous work done in the Punjab revealed that applications of phosphate and potash to cotton proved ineffective while the response to nitr[illegible] varied from place to place and season [illegible]eason [Vaidyanathan, 1934, and Dept. of Agriculture, Punjab, 1936]. In certain cases the response was spectacular, in others meagre. These findings were important inasmuch as they suggested the elimination of the two major nutrients, phosphates and potash, from any manurial programme, but they were of restricted value as no definite conclusion could be arrived at with respect to nitrogen application as a general practice. The causes for the variations in the utility of nitrogenous manures ought to be explained before they could be recommended for wide adoption.

The low nitrogen status of the soils in India gave Crowther [1939] the impression of great prospects of the use of the sulphate of ammonia in this country. Experience in the Punjab has, however, shown that low nitrogen content of the soil is not always attended with high response to this fertilizer in case of cotton. The success or the failure of manuring depends not only on the knowledge of the nutrient limiting but also on the controlling influence of the other factors associated with it. These factors may be different in the different countries and hence require independent study.

It has already been pointed out [Dastur, 1941] that deficiency of nitrogen produces *tirak* symptoms in the Punjab-American cottons on light sandy soils. The effect of nitrogen application as sulphate of ammonia, in combination with varying levels of other factors, was therefore studied on the different soil types, in a large number of complex experiments conducted during 1937-1942 in the course of *tirak* investigations. The results of some of the experiments showing the effect of nitrogen on the various phases of plant activity on light sandy soils have since been reported [Dastur and Mukhtar Singh, 1943, 1944]. The present contribution is devoted to a concise account of the practical aspects of cotton manuring based on the results of the numerous experiments distributed over the important American-cotton growing tracts of the province.

Investigation

In all about 40 replicated field trials on lands representing different soil conditions were conducted. Nearly 60 per cent of them were carried out on the Departmental Agricultural farms and the rest at private estates. The experiments were mainly of the multiple-factor type. Sowing date as a factor was introduced in bulk of the trials as preliminary studies had shown this factor to greatly influence the yield and the boll opening of cotton. A few experiments also included spacing types. The relation of nitrogen with other factors such as variety, watering, phosphorus, potash, etc. was also explored. Some experiments also provided information as to the time of application, the levels, and the forms of nitrogen.

Relevant information pertaining to the individual experiments and the nature of the soil under them is consolidated in Table I (A and B). In majority of cases, soil samples were taken before the experiments were laid out and were later analysed to determine the nature of soil conditions. In a few cases, however, the characteristic symptoms of the plants and the texture of the surface soil broadly indicated the soil type.

* The investigations described in this paper were carried out in the Punjab Physiological (Cotton Failure) Scheme financed jointly by the Indian Central Cotton Committee and the Punjab Government

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The yields of the control and the manured plots, averaged over all levels of the remaining factors, and the mean response to nitrogen along with appropriate standard errors are also given in the last three columns of the table. The experiments have been grouped according as : (A) the increase in yield with nitrogen was high or medium and definitely profitable, (B) the response was low or nil involving monetary loss. The price of the sulphate of ammonia has been taken at its pre-war rate of Rs. 5 per maund (82·2 lb.) and that of seed cotton at its lowest value of Rs. 7 per maund.

TABLE I (A)

Experiments in which the response to the sulphate of ammonia was high and profitable

Expt. No.	Station	Year	Soil type	Previous crop	Factors studied in addition to nitrogen	Dose of sulphate of ammonia with time of application	Yield of *kapas* in maunds per acre	Response over control	S. E. of response
1	Lyallpur Agricultural Farm	1937	Light sandy	Fallow	Phosphorus, potash, F.Y.M., watering	Control 1½ md. at sowing + 1½ md. at flowering	19·25 22·74	3·49**	0·55
2	Ditto.	1938	Ditto.	Oilseeds	Phosphorus, potash, watering	Control 3 md. at sowing 3 md. at flowering 3 md. at sowing + 3 md. at flowering.	12·86 20·96 22·11 25.82	8·10** 9·25** 12·96**	1·03
3	Ditto.	1939	Ditto	,,	Sowing date, spacing, watering	Control 3 md. at flowering	7·94 13·95	6·01**	0·49
4	Ditto.	,,	Light sandy with alkaline subsoil	,,	Sowing date, organic manures	Control 1½ md. at sowing + 1½ md. at flowering.	4·31 7·50	3·19**	0.88
5	Ditto.	,,	Light sandy with mediumly saline subsoil	,,	Phosphorus and potash, sowing date, variety, spacing	Control 1½ md. at flowering.	9·94 13·26	3·32**	0·32
6	Ditto.	1940	Light sandy with alkali patches	,,	Sowing date, variety, time of application	Control 1 md. 2 md. 3 md.	8·52 9·52 11·34 13·27	1·00 2·82* 4·75**	1·19
7	Ditto.	1941	Light sandy	,,	Sowing date, variety, spacing	Control 3 md. at sowing 3 md. at flowering	16·89 22·25 22·14	5·36** 5·25**	0·46
8	Ditto.	,,	Ditto.	Wheat	Sowing date, variety, watering	Control 3 md. at flowering	9·87 18·44	8·57**	0·25
9	Ditto.	,,	Ditto.	Oilseeds	..	Control 3 md. at sowing 6 md. at sowing	17·63 25·21 25·31	7·58** 7·68**	0·80
10	Ditto.	1942	Ditto.	,,	F.Y.M., molasses	Control 3 md. at flowering	15·58 18·68	3·10**	0·45
11	Ditto.	,,	Ditto.	,,	Sowing date	Control 2 md. at sowing 4 md. at sowing 2 md. at flowering 4 md. at flowering	7·64 10·58 12·27 10·48 12·54	2·94** 4·63** 2·84** 4·90**	0·65
12	Sargodha New Seed Farm	1940	Light sandy with saline subsoil	,,	Sowing date, variety, watering	Control 2 md. at flowering.	8·52 10·53	2·01**	0·53
13	Ditto.	1941	Ditto.	,,	Sowing date, variety	Control 2 md. at flowering	9·36 12·26	2·90**	0·57
14	Abdul Hakim (Multan)	1939	Light sandy soil with saline patches	Cotton	Sowing date, variety, watering	Control 2 md. at flowering	9·55 14·34	4·79**	0·41
15	Multan Agri. Farm	1941	Light sandy	Wheat	Sowing date, variety, spacing	Control 2 md. at flowering	9·50 15·00	5·50**	0·84
16	B. C. G. A. Farm, Khanewal (Multan)	1942	Light sandy with saline subsoil and *kalar* patches	Cotton	Phosphorus, potash, sowing date	Control 2 md. at flowering	17·05 19·15	2·10**	0·55
17	S. B. S. Ujjal Singh's Farm, Mian Channu (Multan)	,,	Light sandy with saline subsoil	Gram following reclamation by rice	Sowing date, variety	Control 2 md. at sowing 2 md. at flowering	8·82 10·40 11·98	1·58** 3·16**	0·49
18	Convillepur Farm (Montgomery)	1940	Ditto.	Gram, Berseem, Wheat	Sowing date, variety	Control 2 md. at flowering	14·03 16·84	2·81**	0·57
19	Military Farm, Okara (Montgomery)	1942	Ditto.	Cotton	Phosphorus, potash, sowing date	Control 2 md. at flowering	11·84 15·17	3·33**	0·39
20	Iqbalnagar Estate (Montgomery)	,,	Light sandy	,,	Sowing date, variety, organic manures	Control 3 md. at flowering	15·59 18·83	3·24**	0·67

TABLE I (B)

Experiments in which the response to sulphate of ammonia was low involving monetary loss

Expt. No.	Station	Year	Soil type	Previous crop	Factors studied in addition to nitrogen	Dose of sulphate of ammonia and the time of application	Yield of *kapas* in maunds per acre	Response over control	S. E. of response
21	Lyallpur Agricultural Farm	1937	Light sandy with saline subsoil	Oilseeds	..	Control 3 md. after sowing	4·17 5·03	0·86	0·90
22	Ditto.	1938	Ditto.	Cotton	Potash, presowing watering, organic manures	Control 1½ md. before sowing + 3 md. at flowering	7·64 11·25	3·61*	1·51
23	Ditto.	,,	Sandy loam with saline subsoil	Fallow	Sowing date, organic manures	Control 3 md. at sowing	21·20 22·95	1·75	2·16
24	Ditto.	1939	Ditto.	Cotton	Organic manures	Control 1½ md. at sowing + 1½ md. at flowering	4·01 5·10	1·09	2·82
25	Ditto.	,,	Ditto.	Fallow	Sowing date, watering spacing	Control 3 md. at flowering	13·82 13·41	—0·41	1·06
26	Ditto.	1941	Ditto.	Cotton	Phosphorus, potash	Control 2½ md. at flowering	21·66 22·89	1·23	3·03
27	Ditto.	1942	Ditto.	,,	Sowing date	Control 3 md. at flowering	15·09 15·68	0·59	0·66
28	Ditto.	,,	Light sandy with saline subsoil	,,	Organic manures	Control 3 md. at flowering	8·82 10·77	1·95	1·48
29	Pirmahal, 680/21 Chak (LYP)	1939	Saline subsoil	Sorghum	Sowing date	Control 2 md. at flowering	6·9 7·6	0·7	..
30	Brucepur Farm (Lyallpur)	1940	Sandy loam with saline subsoil	Fallow, gram	Sowing date, variety, watering	Control 2 md. at flowering	14·52 15·67	1·15	1·02
31	B. C. G. A. Farm, Khanewal (Multan)	1939	Light sandy with saline subsoil and *kalar* patches	Cotton	Sowing date, watering	Control 2 md. at flowering	1·48 1·68	0·20*	0·09
32	Ditto.	1940	Ditto.	Wheat	Sowing date, variety, watering	Control 2 md. at flowering	13·35 15·13	1·78**	0·55
33	Ditto.	1941	Ditto.	Fallow	Phosphorus, potash, sowing date	Control 2 md. at flowering	6·57 7·40	0·83**	0·22
34	Military Farm, Okara (Montgomery)	1939	Ditto.	*Toria*, gram, berseem	Sowing date, watering	Control 1·9 md. at flowering	4·36 4·94	0·58	..
35	Ditto.	1941	Ditto.	Cotton	Phosphorus, potash, sowing date	Control 2 md. at flowering	9·20 10·69	1·49**	0·26
36	Montgomery (Chak 90/9L)	1939	Highly saline subsoil	,,	Sowing date, watering, variety	Control 2 md. at flowering	7·08 7·95	0·87**	0·29
37	Montgomery Agricultural Farm	,,	Highly saline subsoil with patches of *kalar*	,,	Sowing date, watering	Control 3 md. at flowering	1·32 1·42	0·10	0·17

A study of the results given in Table I (A & B) will show that the response to manuring with sulphate of ammonia on yield was high and profitable in 20 experiments while it was low and unprofitable in the remaining 17 experiments. Thus chances for the success and the failure of manuring cotton in the Punjab were found to be nearly equal.

It could also be seen from Table I that the increase in yield obtained by the application of a unit dose of sulphate of ammonia was not governed by the general yielding capacity of a field. Fields producing as low as 1 to 5 md. of *kapas* per acre have either not responded to manuring or have given a low response (Expts. 21, 24, 29, 31, 33, 34, 37), while fields with a higher yielding capacity have been found to give high and profitable returns with the application of sulphate of ammonia (Expts. 2, 3, 7, 8, 9, 14, 15). Thus the level of yield in a field was no index for manuring of cotton in the Punjab. It indicated that soil factors other than nitrogen status of the soil operated in determining the response to manuring. The investigations carried out in the Punjab Physiological (Cotton Failure) Scheme have made it possible to distinguish the soil conditions where manuring would be profitable and where it would involve monetary loss.

Soil conditions

A study of the soil in several parts of the Punjab in relation to the effect produced by the sulphate of ammonia on the growth and yield of cotton revealed that on light sandy soils free from subsoil salinity or alkalinity a very heavy response to manuring was obtained. The response was particularly high if the cotton followed wheat or an oilseed crop (Table IA). The increase in yield was of a medium order if such fields were allowed to recuperate through fallowing (Expt. 1).

Salinity or alkalinity or high *p*H in the subsoil was found to affect adversely the response to manuring. Although the fields having these subsoil conditions differed widely in their yielding capacity without manuring, the application of sulphate of ammonia was found to be unprofitable in all cases (Table IB). This held good for the organic manures as well (Table VIII).

The above two soil conditions are found irregularly distributed in the cotton fields. Fields with light sandy soil may also possess patches of subsoil salinity or alkalinity in varying proportions. The average increase in yield by manuring such a field would, therefore, depend on the relative proportion of such areas present in subsoil. The variations in response to manu can be partly understood in the light of the ab findings. It also indicates why a general rec mendation for manuring of cotton in the Pun could not be made as was done for Egypt Crowther *et al.* [1937]. Other relevant fact found to influence the response to manuring light sandy soil are briefly mentioned belo

Varieties

Whereas the *desi* variety, Moll. 39 (*G. indicu* gave a high and profitable response to nitrog on all soil types, the ability of the Punjab-Americ cottons (*G. hirsutum*) to give such increases yield with manuring was greatly restricted the subsoil conditions (Table II).

Another important fact that emerged from th study was that the response to nitrogen on t different varieties varied in the order of the yielding capacity. Of all cottons, Moll. 39 ga the maximum yield as well as the highest respon to nitrogen in all cases except in Expt. 14 whe the germination and the subsequent stand of t variety was poor on account of patches of alk on the soil surface.

L.S.S. yields were heavier than 4F and t response to nitrogen was also found to be great in the former than in the latter (Expts. 7, 12, 1 The remaining strains, viz. 289F/43, 289F/K and 289F/124 did neither differ significantly their yielding capacity nor in their responsiven to nitrogen.

Sowing time

The sowing time of cotton was another fact that governed the response to manuring. was found that generally May-sown crop ga higher increases in yield by manuring than t June-sown crop (Table III). The reduction the magnitude of response was specially mark in the crop sown during the second half of Jun If the soils were extremely deficient in nitrog as in Expts. 14, 15, 17 and 18, all the sowings ga equally pronounced increases in yield by manu ing. With higher doses of sulphate of ammon on such fields the same relationship of sowi time with nitrogen application would have pr bably held good. As June sowings of Americ cottons have now been recommended as a preve tive measure against *tirak*, this aspect of manuri must be clearly borne in mind.

TABLE II

Increase in yield with the sulphate of ammonia under different varieties and its relation to their yielding capacity

Expt. No.	Dose of manure at flowering (md. per acre)	Increase in yield with manure (md. per acre)						S.E.	Order of varietal mean yields
		Moll. 39	4F	L.S.S.	289F 43	289F K25	289F 124		
5 (Lyallpur)	1½	3·98*	2·66**	..	..	..	..	0·45	Moll. 39 > 4F
7 ,,	3	..	5·28**	5·56**	4·89**	..	..	0·80	L.S.S. > 4F > 43F
8 ,,	3	10·66**	6·47**	..	..	..	..	0·36	Moll. 39 > 4F
12 (Sargodha)	2	4·00**	1·48	2·36*	0·22	..	..	0·95	Moll. 39 > L.S.S. > 4F > 43F
13 ,,	2	..	1·80*	3·09**	..	..	..	0·81	L.S.S > 4F
14 (Multan)	2	3·43**	6·16**	..	..	..	..	0·58	4F > Moll. 39
15 ,,	2	..	..	..	4·14**	7·35**	5·01**	1·45	Varieties and varieties × nitrogen insignificant
17 ,,	2	..	..	..	3·08**	3·43**	2·07**	0·84	
18 (Montgomery)	2	5·78**	..	..	2·34**	0·30	..	0·82	Moll. 39 > 43F > K25
20 ,,	3	..	..	..	3·17**	..	3·32**	0·82	Varieties insignificant
30 (Lyallpur)	2	2·49	..	0·92	0·05	..	..	1·33	Moll. 39 > L.S.S. > 43F
32 (Multan)	2	3·75**	..	..	0·79	0·78	..	0·98	Moll. 39 > K25 > 43F
36 (Montgomery)	2	1·22**	0·54	..	..	..	..	0·29	Moll. 39 > 4F

TABLE III

Variation in yield response to the sulphate of ammonia with changing sowing date

Expt. No.	Dose of manure at flowering (md. per acre)	Increase in yield with manure (md. per acre)				S.E.
		1—15 May	16—31 May	1—15 June	After 15 June	
3	3	(12 May) 7·85**	..	(2 June) 6·88**	(22 June) 3·29**	0·85
4	1½ + 1½ at sowing	(1 May) 4·36**	..	(1 June) 2·03	..	1·25
5	1½	(6 May) 4·08**	..	(10 June) 2·55**	..	0·45
6	3	(10 May) 5·37**	(28 May) 5·84**	(15 June) 3·03*	..	1·27
7	3	(15 May) 6·89**	(31 May) 5·05**	..	(20 June) 3·79**	0·80
8	3	(15 May) 9·22**	..	(10 June) 7·91**	..	0·36
11	2	..	(21 May) 4·85**	(11 June) 2·45*	(2 July) 1·21	1·13
11	4	..	(21 May) 7·70**	(11 June) 5·21**	(2 July) 1·80	1·13
12	2	(15 May) 2·87**	(30 May) 3·85**	(15 June) 1·41	(30 June) 0·08	1·06
13	2	(15 May) 3·83**	..	(2 June) 3·25**	(19 June) 1·60*	0·81
14	2	..	(18 May) 4·67**	..	(18 June) 4·93**	0·58
15	2	..	(19 May) 4·51**	(6 June) 4·95**	(24 June) 7·04**	1·45
16	2	..	(20 May) 2·46**	..	(20 June) 1·73*	0·77
17	2	..	(18 May) 4·02**	(12 June) 2·05*	(28 June) 3·41**	0·84
18	2	(8 May) 3·15*	(23 May) 2·50*	(7 June) 3·52**	(22 June) 2·05	1·14
19	2	(13 May) 4·50**	..	..	(20 June) 2·18**	0·55
20	3	..	(20 May) 5·24**	(7 June) 2·31*	(27 June) 2·19	1·15

Spacing

There was an indication that for manurial response May-sown crop behaved indifferently to spacing, but close spacing was specially conducive to better fertilizer response in the case of June-sowings. The experimental evidence in favour of this view is, however, still not conclusive.

Watering

Heavy watering greatly favoured the effectiveness of manure in Expt. 1 where the field was allowed to recuperate through fallowing prior to sowing cotton. Under intensive system of cropping, however, nitrogen alone acted as a limiting factor and the increases in yield with the artificial fertilizer were so heavy under normal watering that further improvement in response through extra dose of water was meagre (Expts. 2, 3, 8, 14). Hence heavy watering on nitrogen deficient soils would not be of much benefit whether given with or without the application of a nitrogenous fertilizer.

Time of application

Optimum time for the application of the sulphate of ammonia was unmistakably mid-August for the May-sown cottons. This confirms the previous experience in the Punjab. The differences in favour of August application were less marked as the sowings were delayed, so much so that in a few cases (Expts. 7, 11) application before sowing proved slightly superior for the late sowing.

Dose of manure

There were only a few trials involving the comparisons of the different doses of ammonium sulphate. A study of Table I reveals that the increase in yield is linear up to 3 md. of manure per acre (Expt. 6). The response trend shows a decline with higher rates of application (Expt. 11), and 6 md. of sulphate of ammonia is undoubtedly an over doze (Expts. 2, 9). In the experiments under review, the dose employed was 2-3 md. The results obtained and discussed, therefore, are of general practical value.

Effect of phosphatic and potassic fertilizers

There were seven trials to study the effect of the fertilizers with and without nitrogen. Two experiments were repeated on the same sites to find out the residual effect, if any. In spite of the heavy doses used, the direct as well as the residual effects of these fertilizers were insignificant in all cases (Table IV). In view of these results and those already obtained by the Department of Agriculture, it can safely be concluded that the Punjab soils do not lack in phosphorus or potash. Besides, none of these fertilizers interacted with nitrogen the level of which alone determined the final yield.

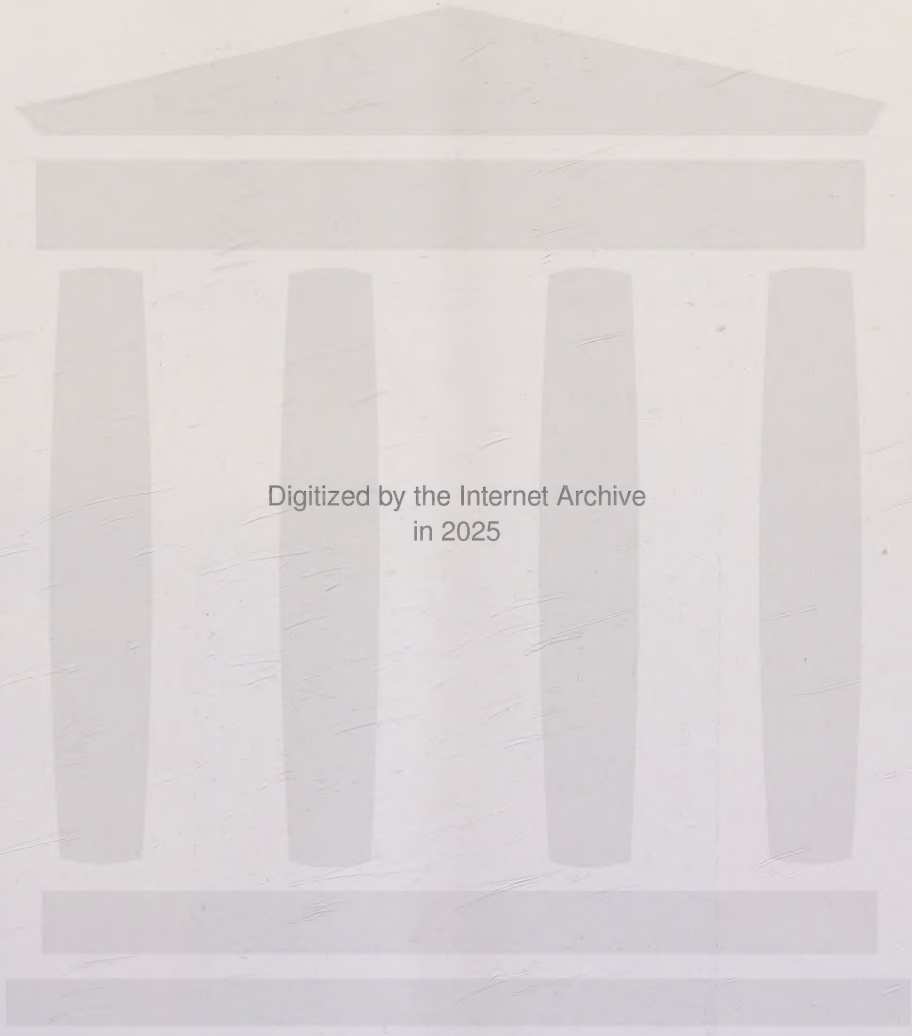
Table IV

Effect of phosphorus and potash on the yield of cotton

Expt. No.	Dose of phosphate lb. P_2O_5 per acre	Dose of potash lb. K_2O per acre	Yield of *kapas* in maunds per acre				S.E. of mean
			Control	Phosphorus	Potash	Phosphorus + Potash	
1	120	48	20·3	21·7	20·6	21·4	0·55
2	100	200	20·4	19·9	20·7	20·8	0·78
5	50	50	11·2	..	..	12·0	0·38
22	..	360	8·98	..	11·2	..	1·07
26	100	200	22·5	22·4	21·7	22·4	3·03
33	200	230	7·44	6·95	6·99	6·56	0·69
35	200	230	10·8	9·25	9·44	10·3	0·44
16 Residual effect of Expt. 33		..	17·6	17·8	19·1	17·9	1·17
19 Residual effect of Expt. 35		..	13·0	13·5	13·8	13·7	0·63

Effect of organic manures

Farmyard manure and berseem green manure were tried in a few experiments. The results are summarized in Table V. The absence of response in Expt. 1 was attributable to three factors, viz. (1) cotton followed cultivated fallow, (2) the dose was small, and (3) this treatment was relegated to the main plots. The soil under Expts. 23, 24 being sandy loam and saline was responsible for the failure of response to manuring. In other experiments the increases in yield were substantial as the soil underneath was light and sandy. Thus these manures behaved in the same manner as did the sulphate of ammonia in relation to soil conditions.



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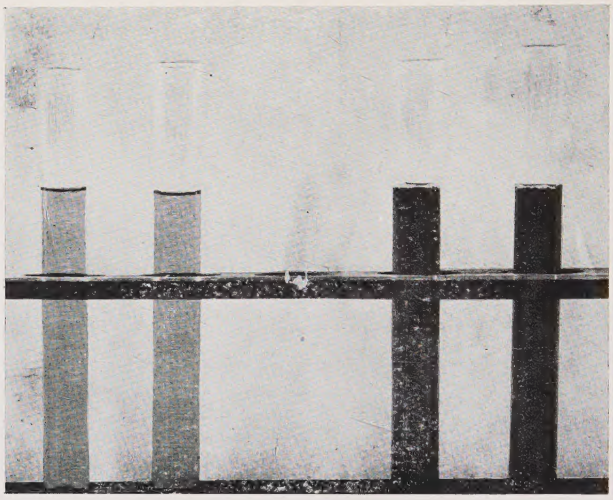

FIG. 1. The photograph of leaf extracts giving the negative 'tannin' reaction (left) and positive 'tannin' reaction (right)

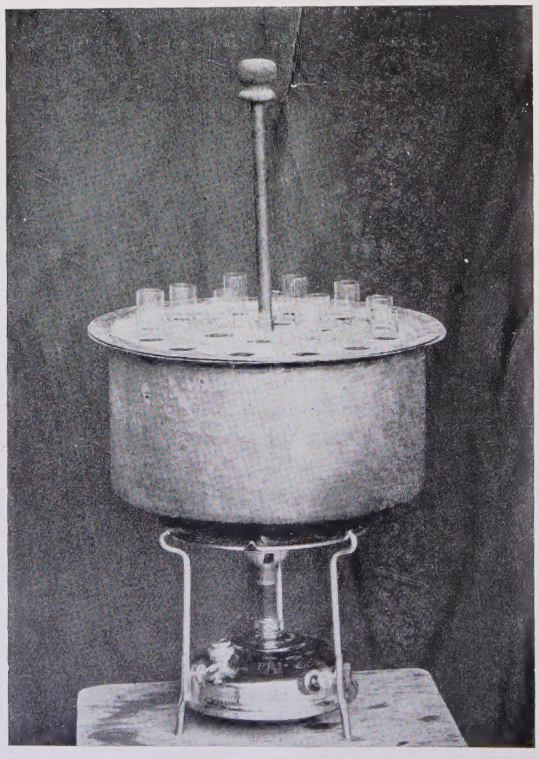

FIG. 2. The apparatus for preparing leaf extract for tannin test. 16 samples can be extracted at a time by means of this apparatus.

TABLE V

Effect of Farmyard manure and berseem green manure on the yield of cotton

Expt. No.	Dose (tons per acre)	Yield of *kapas* in maunds per acre			Response	S.E.
		Control	Farm yard manure	Berseem green manure		
1	5	20·7	21·3	..	+0·6	0·78
4	10	4·31	..	7·31	+3·0**	0·88
10	20	13·4	22·6	..	+9·2**	0·90
22	20	7·64	11·86	10·05	4·22 2·41	1·51
23	10	21·2	19·5	..	—1·7	2·16
24	10	4·01	..	3·41	—0·60	2·82

On account of the non-availability of the sulphate of ammonia under the present war situation, the comparative manurial value of oil-cakes and ammonium sulphate was studied in the year 1942. Quantities of manures to supply 50 lb. N per acre were calculated and added. *Toria* cake though slightly inferior to the sulphate of ammonia on equivalent nitrogen basis proved to be a good substitute for the latter (Table VI). Cotton cake did not hold out promise of extensive use. There was an indication from Expt. 38 that *toria* cake should preferably be applied before sowing. Further work is, however, necessary to confirm these findings and to work out the economics of *toria* cake.

TABLE VI

Comparative effects of ammonium sulphate and oil-cakes on the yield of cotton

Expt. No.	Time of application of oil cakes	Yield of *kapas* in maunds per acre				S.E. of mean
		Control	*Ammonium sulphate	*Toria* cake	Cotton cake	
10	At flowering .	13·24	17·02	16·10	..	0·38
20	At sowing .	15·59	18·88	17·69	16·64	0·35
28	Ditto. .	8·82	10·77	9·57	8·14	1·04
38 (*a*)	Ditto. .	11·24	..	16·29	..	0·33
38 (*b*)	At flowering .	..	..	15·87	..	..

* Applied in all cases at flowering in the middle of August

A PRACTICAL METHOD FOR DETECTING NITROGEN-DEFICIENT FIELDS

Manuring of American cottons in the Punjab could be profitably undertaken on light sandy soils free from subsoil salinity. This finding could not be put to practical use as it was impossible for a zemindar to know the soil conditions and to exclude from manurial programme such fields as were not likely to yield profitable returns. Besides, the yielding capacity of a field was shown to be no criterion for manuring it. During the course of investigations carried out in the Punjab Physiological Scheme, a simple and inexpensive method has been found to detect cotton-fields which would give profitable increases in yield by manuring with ammonium sulphate. This method is termed as 'tannin test', and is described below:

In the month of August six cotton plants are selected at random from one-fourth of an acre and 30 discs are cut out from mature leaves by means of a leaf punch. They are transferred to a tube containing about ½ oz. of water and the tube is kept for 2 hr. in a hot water bath. When the extract of the leaf discs cools down, it is treated with 5 drops of an aqueous solution of osmic acid (1 gm. of osmic acid dissolved in 4½ lb. or 2 litres of water). Two drops of dilute sulphuric acid are then added to the extract. If a blue green to a dark brown colour (Plate XI, fig. 1) is produced, the crop requires nitrogen manuring. If the leaf extract remains yellow or orange-red, manuring is not necessary. Apparatus required to handle 16 samples at a time is given in Plate XI, fig. 2. The cost of making this test works out to be about one anna per sample at the pre-war rates of the chemicals, etc. used.

'Tannin test' has been tried out extensively for three successive years on the fields of zemindars in the different cotton-growing tracts of the Punjab, and found to be very successful. The details of the tests made and the results obtained are given in Table VII.

TABLE VII

Statement of tannin tests made and the results obtained

Year	Total No. of tests made	No. of positive tests	No. of fields selected for manuring	Dose of sulphate of amm. md. per acre	Yield of *kapas* md. per acre		Increase
					Control	Manured	
1939	45	22	15	2	7·21	11·21	4·0
1940	265	123	55	2	10·48	12·66	2·18
1941	326	173	22	2	11·38	14·24	2·86

The results show that it would be profitable to apply sulphate of ammonia to the fields that give the test. In 1940 the magnitude of increase was relatively small as majority of fields selected for the test and subsequent manuring had already turned very pale so that it was too late to correct the internal disorder in the plants at such an advanced stage of nitrogen starvation. Fields selected for the test should be light green and should possess perfect stand in order to obtain best results from manuring. It may be mentioned that this test for manuring cotton has only been found successful in the Punjab. It is possible that similar results may not be obtained in other cotton tracts.

Conclusions

The problem of manuring cotton centres round the availability and the application of nitrogenous manures as phosphorus and potash have not generally been found to be limiting. Nevertheless the problem did not prove to be quite simple as the magnitude of response to nitrogen was found to be governed by a multitude of factors of which the soil was most important. While the *desi* variety could profitably be manured on a wide range of soil conditions, the American cottons responded only on light sandy soils free from subsoil *kalar*. On sandy loam fields with saline or alkaline subsoil the response was either low or nil. The increase in yield was of a medium order when light sandy lands had also some alkali concentration in the subsoil. Where the different soil conditions were found intermixed, the relative proportion of each determined the ultimate gain from the application of nitrogen. This finding explains at least in part the cause of wide variations in the results obtained with nitrogenous fertilizers and the difficulty experienced in making a general recommendation for cotton manuring.

The original nitrogen status of the soil is no less important, provided other soil factors are favourable. The increase in any crop produced by a unit increment of a deficient factor is proportional to the decrement of that factor from the maximum (Mitsherlich). Practices such as fallowing, restorative rotations providing legumes, green manuring and the use of other organic manures that raise the nitrogen level of the soil make it less and less responsive to the application of nitrogen.

A simple and expeditious device designated as the ' tannin test ' has been evolved and described, the use of which enables one to detect fields suffering from nitrogen deficiency without recourse to soil analysis. This biochemical test is applied to the aqueous extract of the leaf just before the onset of flowering. Once the positive test is obtained, sulphate of ammonia can be applied at the rate of 2-3 md. per acre.

The influence of sowing date, spacing, and variety in modifying the response to nitrogen on light sandy soils cannot be ignored. May-sowings possess greater potentiality for increase in yield through manuring than the June-sowings. The usefulness of nitrogen falls off as the sowing date advances so much so that the June-end sowings derive the least benefit. The manurial response to late sowings can, however, be greatly improved by close spacing.

The different strains of cotton were found to respond to nitrogen in the order of their yielding capacity, i.e. greater the yield, greater the response and vice versa.

The behaviour of the organic manures in relation to the soil conditions was similar to that of ammonium sulphate, and from one year's trial *toria* cake appears to be a good substitute for this inorganic fertilizer.

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COMPARATIVE STUDIES ON INDIAN SOILS

I. REGIONAL AND ENVIRONMENTAL FACTORS ASSOCIATED WITH INDIAN SOILS

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The work on this subject is reported in a series of topics. It represents the coordinated team work in the Chemical Section of the Imperial Agricultural Research Institute under the direction of the senior author and is designed to form the basis for the interpretation of Indian soils in the light of modern developments in soil science both in its theoretical and practical aspects. To this end comparative data are obtained on the relevant physico-chemical and bio-chemical properties of soils in relation to colour, climate, geographic distribution and life in the soil.—B.V.N.

Object and scope of the enquiry

Farming, whether intensive or extensive, requires knowledge of soil factors for handling soil questions. As knowledge of soils increases, more rational and more economic methods become available for the reclamation and utilization of new and derelict lands; the practice of growing crops unsuited to any particular soil can be prevented; better use can be made of manures, fertilizers and irrigation waters; there will be improvement in farming whose welfare is linked up not only with the quantitative and qualitative aspects of production but also with economic conditions in respect of costs and prices.

In India, we have stabilized soils and long established agricultural systems and practices many of which are scientifically and economically sound. The practical knowledge that accumulated through long experience and tradition was, till the beginning of the present century, the sole factor that governed the distribution and management of crop and animal husbandry in the different regions of the country.

A forward move became possible with the establishment of agricultural research institutes 40 years ago, and the scientific study of Indian soils has been in progress since then. In those days the terms 'pedology' and 'soil science' were not known. The scientific ideas on soils were based largely on one or the other of two view points. One view was largely influenced by Liebig's mineral theory of plant nutrition, and looked upon soil principally as a chemical nutrient medium for crop growth; the other view held the soil as the surface modification of the geological formation. The former view prevailed with the agricultural scientists. Soil studies began, therefore, with the more obvious problems of soil fertility in terms of sufficiency and deficiency of fertilizer constituents and studies on soils were concerned principally with the chemical, physical and micro-biological properties of surface and subsoils. On the basis of these studies four major types of soils have been distinguished, namely the Indo-Gangetic alluvium, the black or *regur* soils, red soils and laterite soils. Each of these major types has its sub-types.

During the last two or three decades, the second view gained ground. Its ideas are similar to those of geology in the sense that they deal with the evolution of soils. Under the new concept, the soil is recognized as a dynamic body subject to perpetual changes and the future of the soil can be visualized from a knowledge of its past evolutionary changes. Originated by Glinka in Russia, tested and modified by Marbut for conditions obtaining in U.S.A. and by Ramann in Germany, the new concept rapidly gained ground and influenced soil research and thought in other parts of the world. The substance of the new concept is that the soil from the surface down to the parent rock below is considered as a natural body made up of parts which have grown or evolved together under the influence of the prevailing environment. There are forces at work making the soil and its body which is something different from transported or sedimented or deposited material. Prominence is given to the study of soil dynamics and regard is paid to the descriptive metamorphism of the soil profile, to understand the processes of changes concerned in the developmental history and morphology of the soil profile or section.

These developments which are very suggestive attracted attention in this country and influenced soil research in its scientific and applied aspects, and induced us to apply the methods in the study of our soils. Detailed studies are made on soil profiles in relation to the chemistry, physics and micro-biology concerned in the development of

profiles, horizons and in their structure, colour and other characteristics, and a large volume of data has accumulated. The time has come for the systematization and assimilation of the available data into farming practices and to fit our soils into the world scheme of soil classification and terminology.

An important feature of modern soil science is that it does not now speak of soil in terms of wheat soil, paddy soil, cotton soil and so on. Soils are classified and named on the basis of the distinguishing characteristics of the soil profiles which have developed under natural conditions. The scientific point of view cannot, however, be separated from the agricultural point of view. Much of the significance is lost if the new system is not related to the practical aspects of agriculture. Indian soils are largely under relatively dry tropical and sub-tropical conditions. There is in vogue the colour classification which, though empirical, signifies correctly major characteristics and agricultural practice associated with the soils. The farmers recognize different kinds of soils on the basis of differences in the management of soils and their productivity and their agricultural practices are governed largely by these considerations. The general and local names given by the farmers to their soils are descriptive and tell with a reasonable degree of precision the agricultural properties of the soil. It is, therefore, important to ascertain to what extent soils differentiated on the basis of their workability and productivity correspond to types classified according to modern soil science. In other words, we should endeavour to correlate the new system with actual farming in the country, in order that the farmer and the soil scientist in India may speak common soil-language and that the results of research may be utilized for the solution of practical problems. Also, it is desirable to correlate the local terminology with the international nomenclature, for the necessary understanding by soil workers in and outside India.

What has just now been said becomes obvious when it is stated that facts derived from laboratory studies and field experience have revealed that the principle and practices developed elsewhere have been found in many cases unsuitable for application to our soils without substantial modifications. For example, heavy clays which in other countries would be classed as unfit for crop growth are known to yield good crops in India. The nitrogen and phosphate contents of many Indian soils which grow good crops are of an order which would be declared as being deficient in these constituents for the soils of the temperate regions. The nitrogen recuperation powers of Indian soils are greater than those of the temperate regions. Frequent and deep cultivation with or without soil inversion is not always and everywhere followed with economic results and in some cases the results have even been injurious.

It is important, therefore, in order to distinguish between the processes and their intensities in soil and plant growth in temperate and tropical conditions, the available data should be co-ordinated in order to have more precise and comparative information for the interpretation of soils and their performances and to ascertain how far Indian soils fit into the world scheme of soil classification and terminology. The available data of the past were obtained on different samples collected at different times and examined by different methods. Also the studies of the early days were made under the older concepts. It is, therefore, unsound to rely on the available data in comparative soil investigations for assessing the scope of recent developments in soil science either in the evolution of new principles and practices or in the modification of older ones. The first step then is to secure comparative analytical data by identical methods of collection of samples and their analysis.

The object of the study, therefore, is to obtain in the first instance, data on the characteristics of soils to ascertain relationships between them and between the horizons in individual profiles. The data will then form the basis for the interpretation of soils, and the effects of manures, fertilizers, irrigation and plant response. Such information will be found useful to students of soil science and to students of agronomy to whom more knowledge of our soils is a matter of increasing interest and importance.

To this end samples of soils, from virgin and cultivated areas from the localities where experiment stations exist in different parts of India, were collected by the members of the Section in the same year and in the same month. The places where experiment stations exist have been selected so that the crop data available at those places may be made use of in interpreting the soil data. Stress has been laid on the importance of uniformity in the description of the profiles, collection and preparation of soil samples which

ere analysed by experienced analysts, employing pproved and established methods of analysis.

The scope of the enquiry is limited, in the first istance, to the study of soils which have not een under cultivation, the changes which profiles ndergo with variations in temperature and ntermittent aridity, hydrostatic pressure and ther variable conditions. These variables in- ividually and jointly control the transformations n the regional soils. The scope of enquiry is, herefore, designed to secure comparative data n the nature, geological, physical and chemical omposition, and properties arising under isother- nal and isodynamic conditions and hydrostatic ressure (humidity).

URFACE GEOLOGY AND PROFILE MORPHOLOGY

The soils of India like those of other countries nay be divided into two broad divisions, namely lrift and residual soils, majority being included n the first type. The alluvial soil mantle of northern India and of coastal plains and certain ocalized areas in peninsular India are mostly lrift soils formed by deposition of alluvial and vindborne debris, while a large part of peninsular ndia are residual soils and soils formed *in situ.* ndian soils, however, offer a distinct contrast o those of many other countries in that they re old, mature and do not show generally the edogenic processes and the close relationship etween the soil and its rocky substratum. The reat majority of soils of northern India are of lluvial origin derived from the sedimentary ocks of the Himalayan range of mountains while hose of the peninsular India, which represents he ancient table land are derived from the ancient nd earliest formed gneisses and schists and the Deccan trap rocks.

The earliest investigations by Volclcker at rst in the year 1893 and the later studies by eather [1898] distinguished four major types of oils—the Indo-Gangetic alluvium, the black or *egur* soils, red soils lying on metamorphic rocks, nd the so-called laterite soils. In addition, tretches of alluvium along the coasts and the nouths of the great rivers have been noted to ccur. From his studies on the composition of hese soils, Leather found the brown deltaic lluvium of the great rivers of Deccan and penin- ular India bear no relation to the Indo-Gangetic lluvium and in addition observed that soil overing what is known as the Dharwar system f the Western Ghats or Sahyadri hills to be very much different from the red soils of the meta- morphic rocks. Leather also observed that calcareous soils in the Indo-Gangetic alluvium contained nodular lime stones within a few feet below the surface and also intermixed throughout the soil mass.

The chemical composition of the soil is governed to a large extent by the original composition of the rocks from which the soils are derived and the nature of the chemical processes that have taken place during the formation of soils. The mode of rock formation has also a marked effect on the composition and properties of the resulting soils. A concise statement showing the surface geology of the localities from which the soils were collected is given in Appendix I.

In addition to its geological origin the soil is under the influence of major and minor effects of the phenomena of life in the soil, climate and seasons relative to the geographic coordinants measured and expressed in units of time, distance, temperature and hydrostatic pressure. Under the influence of climate geological differences are obliterated and soils of similar properties cover the most varied rock systems. The more extreme the climate the more generally will the climatic type of soil predominate. Examples are the black soils in India derived from different types of rocks. A mature soil is, therefore, the expression of geo-climatic and geo-biological forces which are jointly operating. The climatic environment impresses itself most on soils formed by the deposition of material transported great distances from the points of origin by the large number of great rivers traversing the country, and by high winds. For the reason that a large majority of soils in India are transported soils and for the reason that to a great extent the soils are in what may be characterized as dry tropics and sub-tropics with alternating periods of extreme aridity and humidity, a study on climatic basis is particularly apposite to Indian soils.

Climate is the nett result of atmospheric factors which make different regions and periods more or less suitable for supporting life. The two im- portant climatic elements that influence soil processes are temperature and humidity. Water is a substance which is very largely concerned with the birth and development of soils and the life supported by the soils. Water takes a high place in two very important physical properties namely, specific heat and heat of evaporation.

Apart from the gross effects of flooding, transportation and leaching of soil material, under comparatively dry conditions water, in the shape of moisture, affects stabilization of temperature. In a dry atmosphere, a moist soil exposed to a rising atmospheric temperature exercises heat-dissipating capacity by virtue of its increasing vapour pressure. The result is that more and more heat is lost by evaporation and the soil acquires heat much more slowly than the surrounding atmosphere. Conversely, it cools down at a slower rate when the external temperature falls. Thus by its comparatively large capacity for heat, water in its various forms exercises control over what is called the climatic effect.

Several workers have from time to time endeavoured to correlate climatic factors with soils and soil processes and properties, and proposed various formulae for expressing the effect of climate (rainfall, humidity and temperature). The simplest and the most satisfactory formula is the one proposed by Meyer [1926] and known as Meyer's factor or humidity factor or N.S.Q. It is the ratio of precipitation or rainfall to the absolute saturation deficiency of the atmosphere. Jenny [1929] used this ratio for the soils of U.S.A. Prescott [1934] has used this in Australia. Recently, Hosking [1937] employed Meyer's factor in his studies on the relationship between the black earths of Australia and black soils of India. Raman and Satukopan [1935] characterized the climate of India by the annual rainfall minus the annual evaporation. Had there been data on effective rainfall (i.e. rainfall minus run off and evaporation) this value would have been more useful than Meyer's N.S.Q. The differentiation of India into broad climatic zones on the basis of N.S.Q. has been found to correspond with the natural adaptation of crops better than any other factor. The correspondence between climatic zonal classification of soils and the zonal adaptation of crops (rice, wheat and millets) is of value as a check and enables us to assess the bio-climatic character of the zone with reference to the type of farming, cultural practices and the type of products best adapted to it. This broad classification is of special value in bringing together under one coordinated system the major and minor groups of soils. In doing so, the object is to determine the characteristics of the soils and their profiles with reference to a zone and to the transition changes, if any, from one zone to another under the influence of factors operating in those zones and if possible and necessar utilize variations, if any, as a basis for interpr in a broad manner the response of soil types t geo-climatic and geo-biological conditions obtai in that zone.

The data for N.S.Q. have been calcul for India with the aid of meteorolo data for India, details of which are give Appendix II. The N.S.Q. divides India lo tudinally into four broad divisions, begin with arid in the extreme west and passing e ward through semi-arid and humid into humid or wet zone in the extreme east of country. It will be noticed that these zones at right angles to the latitude and this is larg because of the Himalayan mountain ranges on north and of the effect of the sea on either side the mountain ranges in the peninsular p of India.

The differerent climatic factors and their lim are shown in Table I.

TABLE I

	Arid	Semi-arid	Humid	Per-hu
Mean temperature °C.	24	26	25·7	24
Limits .	22—27	24—29	24—28	19—
Annual rainfall mm.	335	710	1265	2
Limits .	175—500	500—1040	916—1540	1870—3
Humidity factor (N.S.Q.)	65	144	273	
Limits .	32—102	91—202	203—430	579—17

The climatic factors, which are relatively secondary significance in temperate countri acquire in India a major importance and exerci their influence in a higher degree, both in intensi and duration, than in Europe or Central Asia can be seen from Tables II and III.

TABLE II

Temperature (°C.)

	Cold season (Jan. & Feb.)		Hot season (March to May)		Monsoon S. W. (June to September)		Receding Monsoon N. E. (October t December)	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min
Arid .	21·4	7·0	33·9	18·3	38·0	26·0	28·0	11·
Semi-arid .	27·8	13·1	36·6	22·2	33·5	24·4	29·0	15·
Humid .	27·3	13·9	36·9	22·9	32·1	24·6	28·4	16·
Per-humid .	25·9	13·1	31·5	20·9	31·2	24·4	28·3	17·

It will be seen that the arid region is under ore extremes of temperature than either emi-arid or humid zones where high tempera-ures prevail almost throughout the year. Com-aratively lower and more uniform temperatures re obtainable in the per-humid zone.

TABLE III

Rainfall

	Cold season (Jan. & Feb.)		Hot season (March to May)		Monsoon S. W. (June to September)		Receding Monsoon N. E. (October to December)	
	Rain-fall mm.	Per cent on total	Rain-fall mm.	Per cent on total	Rain-fall mm.	Per cent on total	Rain-fall mm.	Per cent on total
d . .	38·7	11·5	62·7	18·6	218·2	64·6	18·1	5·4
ni-arid .	23·4	3·3	51·8	7·3	523·5	73·9	110·1	15·5
mid .	35·1	2·8	76·3	6·0	1031·9	81·6	121·1	9·6
-humid .	61·5	2·4	494·8	19·1	1841·8	71·2	188·0	7·3

The greatest precipitation takes place in the onsoon period preceded by smaller falls during e hot months. It is realized that the climatic fferentiation of soil zones does not accurately eate the 'azonal' or 'intrazonal' soils. There however, the advantage that the soil type that may be expected under a given climatic regime and the agricultural behaviour of the soil may be known with a reasonable degree of certainty. It is interesting to note that a close correspondence exists between the geographic distribution of black, red and the so-called laterite soils and climatic zonation.

The description of the profiles examined is given in Appendix III. A feature of the field observations is the absence in the soils examined of profiles in the sense in which they are usually understood and described. In the drift soils or alluvial soils there is no clear demarcation of horizons or lines of contact and in many cases there is no close relationship between the soil and its rocky sub-stratum. The type of soil in the different regions is seen to a large extent decided by the climate of that area. For this reason profile samples were collected in foot depths, and where horizons could be differentiated, the samples were collected horizonwise.

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APPENDIX I

Profile No.	Station and popular general description of soil	N.S.Q.	Regional surface geology
1	Peshawar—Silty loam .	69·2	Recent deposits Grey micaceous sandstones, shales, quartz, felspar and mica, Laki limestones of nummulitic origin. Salt ranges close by Kabul River.
2	Haripur (Hazara)—Silty loam .	102·1	Sub-recent deposits—fluviatile, lacustrine and glacial alluvium. Bounded on 3 sides by Attock or Hazara slates which have dark coloured nummulitic limestones, some sandstone and trap. Depositions by the Dor River from the Tertiary and cretaceous systems. Also rhyolitic acid lavas.
3	Lahore—Loam . . .	105·8	Recent deposits of River Ravi which rises in Jammu hills (tertiaries, Puranas, crystalline gneisses, etc.) and passes through meran shales and siwaliks, containing boulder-conglomerates, soft sandstones, red and purple shales.
7	Gurdaspur—Silty loam . .	188·0	Recent deposits. Doab of Ravi and Beas. Beas rises and passes through Himalayan granites and gneisses and siwaliks.
8	Kangra—Silty loam . .	..	Upper tertiary of the Sub-Himalayas; consists of boulder-conglomerates, sands and grit and massive grey sandstone with pale or drab shales (Siwaliks). Glaciers had extended within the district—great thickness of gravel and pebble beds over boulder-conglomerates are seen near Dalhousie.

APPENDIX I—*contd*

Profile No.	Station and popular general description of the soils	N.S.Q.	Regional surface geology
9	Lyallpur—Sandy Loam . .	60·6	Recent deposits ; situated between rivers Ravi and Chen latter rises from the slates and laterites and passes throu and moraines. Coarse boulder-conglomerates occur points of emergence of the large rivers—the Ravi, Ch Jhelum and their principal tributaries. The intervening g occupied by massive beds of sand, grit and brown and r
10	Mianwali—Sandy loam . .	67·1	Gondwanas, Upper Siwaliks and lower Miocene (Murree).
11	Sakrand—Silty loam . .	30·8	Recent deposits. Indus alluvium derived from shales an stones of gypseous and carbonaceous nature, massive num limestones of the Kirthar series, marine yellow limesto shale (fossiliferous) of the Lower Miocene (Gaj series) a sandstones with conglomerates and brown and orang and clays.
12	Karachi—Sandy . . .	35·7	Recent deposits. Sandstones and fossiliferous marine lim marine yellow limestones and shales.
13	Mirpurkhas—Loam . .	32·0	Recent deposits. Indus alluvium.
18	Shahjahanpur—Loam . .	203·1	Recent deposits. Ganges valley chiefly the water worn d the outer Himalayas and the Siwaliks.
19	Padrauna—Sandy loam Low-land.	328·0	Alluvium of River Gandak—one of the oldest river course of which is now carrying down the detritus from a broad band siwaliks.
22	Ranchi—Clay loam Upland .	..	Bengal, gneiss.
24	Nagpur—Clay loam . .	225·0	Situated on the borderland of archean gneisses, deccan tra lower Gondwanas occurring within a distance of about 2 m
25	Akola—Clay loam . . .	141·1	Lower trap of C.P. and Berar. The most common rock of trap is a normal augite-basalt of a greyish green tint-bl lighter shades are also seen.
26	Waraseoni—Loam . . .	275·2	Wain-Ganga basin. Granites and crystalline gneisses of warians and basic trappean intrusions. (Haematite-qua and Mn-epidotes. The yellow colour points to derivation felspathic granites and laterisation is probably due to metaso surface replacement of slates and schists by Mn-bearing tion.)
27	Labhandi—Clay loam . .	237·5	Mahanadi alluvium. Lower Cuddapah or Bijawar series of Ra
28	Chandkhuri—Loam Mahanadi alluvium	246·3	shales slates, quartzites and limestones.
29	Kheri (Adhartal)—Clay loam .	304·6	Older Narbada alluvium. Slope is towards the Nerbada fro Vindhayans and an out crop of the Dharwarians of Ce India.
30	Powarkhera—Clay loam . .	236·8	Older Narbada alluvium. Nerbada valley ; the river trave areas containing trap, Vindhayans, Archaeans and Gondwana different stages.
31	Indore—Clay loam . .	167·3	Southern face of a hillock in the trap area in Malwa ; Ma trap, the most prevalent constituent is normal augite basal
32	Kharna—Clay loam . .	149·9	Malwa trap.
33	Makrera—Sandy loam (Beawar)	104·8	Aravalli, Raialo and Delhi systems. Crystalline gneiss and gran of the Archaean systems.
34	Tabiji—Sandy loam (Ajmere) .	110·2	Raialo and Delhi systems, as also Granites (Acid pegmati and syenites of the Archaean system. Composite gneisses fr slates and phyllites by injection of granites. Archaean sha hornblende-schists and schistose conglomerate resting on t gneiss.
35	Jorhat—Sandy loam . .	1725·7	Recent deposits. Brahmaputra alluvium ; the river passes over zone of Bhabar deposits of stones, gravel and shingle for seve miles before reaching Sibsagar district. A number of ridges ru more or less across the line of the valley down to the Mikir hil These are sandy in character. A series of low hills are scatter in the greater part of the district, are red in colour and gneiss in character. The Jorhat ridge is deep, friable and Sandy.
36	Karimganj—Silty loam . .	1322·7	Recent deposits of Barak river, rising from Naga Hills. Its trib tary Langai rises from Lushai Hills. Both rise from the Tertiari of Eastern India mainly comprised of sandstones, shales, numm litic limestones, argillaceous beds, etc. May also have the effe of Siwaliks containing thick coarse ferrugenous sandstones a sandy clays, etc.

APPENDIX I—*contd.*

Profile No.	Station and popular general description of soil	N.S.Q.	Regional surface geology
37	Sylhet—Sandy loam . .	1191·5	Recent deposits; Surma river, which rises from the Shillong plateau; the Jaintia Hills consisting of sandstones, shales and thin seams of coal and nummulitic limestones with local development of shales and sandstone.
38	Dacca—Loam . . .	579·2	Dacca stands on the bank of River Burhiganga. Recent deposits; Burhi Ganga river. The soil is of the same type as the older alluvium of the Brahmaputra and lower Ganges valleys.
39	Rangpur—Sandy loam . .	694·8	Recent alluvium; Rivers Teesta and Ghaghat, a branch orginally of the Teesta, now beheaded. The Teesta rises from the Dharwarian gneiss and crystallines of Darjeeling and Sikkim. The Teesta used to flow in the 18th century west of Rungpur, through Dinajpur, now it flows through the district in a S.E. direction and falls into the present Brahmaputra river.
40	Chinsura—Clay loam . .	430·1	Recent alluvium. River Bhagirathi, a branch of river Ganges. This tract is continuous with the alluvial area of the east coast and comprises the greater portion of the country to the westward of the Bhagirathi and probably the deposits from the Mor, Brahmani, Adjai and Damodar rivers which bring down materials from the hills of Manbhum, Singhbhum and Santhal Parganas.
43	Sirsi—Sandy loam . . .	886·9	Gneiss and unclassified crystallines, and to the west a stretch of Dharwar series laterites.
48	Padegaon—Clay loam . .	137·0	Desh or dry tract of Poona in the Nira valley. The deposits of the Godavari and Kistna and their tributaries. In the upper reaches are chiefly composed of rolled agates and fragments of basalt derived from the Deccan trap. Accumulation of washings containing fine particles of soil from the Mawal tract (heavy rain) takes place. The prevalent rock of the Poona district is all trap in practically all the varieties.
49	Surat—Clay loam . . .	202·2	Recent deposits; between the rivers Tapti and Narbada; south of Kirthar and Ranikot and West of Deccan trap area. Interstratified beds of gravel or conglomerate containing agate pebble derived from traps and limestone, frequently sandy, argillaceous or ferruginous and abounding in nummulites and other fossils. Some older alluvium of the upper basins of the two rivers, the Nerbada and the Tapti, are also brought down the upper basin covering a considerable depth beneath the levels of the river beds. Laterite beds occur interstratified with the lower Tertiaries near Surat.
50	Coimbatone—Sandy loam .	162·0	Granites and crystalline gneiss. Granitoid, hypersthene bearing rocks of the Charnockite series. Foliated among the gneiss are Nepheline-syanites and their pegmatites.
51	Taliparamba—Loam . .	762·4	Granites and crystalline gneiss of Malabar consisting principally of quartz, felspar, hornblende or mica and garnets and which weather readily into a ferruginous clay.
52	Koilpatti—Clay loam .	154·4	Granites and crystalline gneiss. Kankar and calcareous rocks. (Gypseous). Cuddalore sandstones of Tinnevelly district consisting of highly ferruginous gritty and sandy beds, coloured yellow, brown red or purple and sometimes white or pale-coloured. Clays and shales are interstratified ocassionally.
54	Hagari—Clay loam . .	91·2	River Hagari. Granitoid gneisses and Dharwars. The massive gneisses are of two types—(1) Porphyritoid grey rough gneiss of quartz and pink orthoclase felspar and hornblende, and (2) Red granitoid gneiss of a close-grained aggregate of quartz and felspar.
55	Nandyal—Clay loam . .	127·3	Cuddapah and older paleozoic shales of Kundair group of the Karnul series (Nandyal shales), composed of purple calcareous shales and earthy limestones passing insensibly into compact crypto-crystalline, flaggy limestones (Koilkuntla band). Nandyal shales are soft and crumbling.
56	Samalkot—Loam . . .	223·0	Godavari Delta. Coastal alluvial deposits. Trap and Khondalites.

APPENDIX I—*concld*

Profile No.	Station and popular general description of soil	N.S.Q.	Regional surface geology
57	Anakapalle — Sandy loam Coastal alluvium	182·2	Granites, crystalline gneiss and khondalites. An extensive development of Bezwada gneiss of a dark brownish colour composed principally of lustrous red murchisonite felspar with abundantly scattered garnets. Graphitic schists are also found here and there. Contains some bands of crystalline limestones.
58	Berhampur — Sandy loam Coastal alluvium	301·5	Granites and crystalline gneiss. Charnockite gneiss of the nature of igneous plutonic rocks.
59	Pusa—Sandy loam . .	..	Recent deposits. Boor Gandak River. Alluvium of the Boor Gandak which rises from rocks composed of granites, gneisses and Dharwarians of the Himalayas and passes through a broad belt of the Siwalik foot hills and coastal Tertiary deposits.
60	Delhi—Sandy loam Jumna alluvium	123·6	Triassic-Delhi system of the Aravallis composed of ferruginous and lime quartzites, grits and schistose rocks intruded by large bodies of granite and amphibolites. The schistos rocks consist of biotite schists, phyllites and impure biotitic limestones.

APPENDIX II

Climatic factors

(Compiled from Annual summary of India Weather Review, 1938, Pt. A)

No.	Stations	Temperature				Vapour pressure mm.	Absolute saturation deficit mm.	Yearly rainfall mm.	Humidity per cent	Meyer's N.S.Q.	Lang's R.F.	Elevation in feet above mean sea-level
		Mean max. °F.	Mean min. °F.	Diurnal difference	Average °F.							
1	Peshawar . .	84·7	60·3	24·4	72·5	11·54	4·96	343·2	57	69·2	15·3	1,110
2	Haripur-Hazara .	85·0	60·0	25·0	72·5	11·54	4·96	506·5	57	102·1	22·5	1,730
3	Lahore . .	89·6	60·6	29·0	75·1	12·40	4·71	498·4	62	105·8	20·9	732
4	Ferozepur . .	87·8	64·0	23·8	75·9	12·67	4·44	729·2	65	164·4	29·9	..
5	Kalashakaku .	89·0	60·8	28·2	74·9	12·57	4·53	571·5	64	126·3	24·0	..
6	Gujranwalla .	88·4	61·0	27·4	74·7	12·75	4·34	643·1	66	148·4	27·1	..
7	Gurdaspur . .	88·4	61·9	27·4	74·7	12·57	4·02	755·7	68	188·0	31·9	800
8	Kangra . .	75·0	58·0	17·0	66·5	10·54	2·85	1,869·4	73	653·0	97·4	3,000
9	Lyallpur . .	88·6	62·1	26·5	75·4	12·24	5·51	334·0	55	60·6	13·9	605
10	Mianwali . .	86·9	60·2	26·7	73·6	12·32	4·93	331·0	60	67·1	14·3	750
11	Sakrand . .	93·3	68·2	25·1	80·8	13·84	5·54	170·7	60	30·8	6·3	110
12	Karachi . .	88·0	68·0	20·0	78·0	15·32	5·36	191·5	65	35·7	7·5	49
13	Mirpurkhas .	93·1	68·5	24·6	80·8	13·84	5·54	177·5	60	32·0	6·5	95
14	Aligarh . .	89·1	64·3	24·8	76·7	12·42	5·31	524·3	57	98·2	21·1	..
15	Cawnpore . .	89·9	66·4	23·5	78·2	14·45	4·91	912·4	66	185·7	35·5	..
16	Gorakhpur . .	87·7	66·7	21·0	77·2	16·26	4·07	1,275·0	75	313·6	50·8	..
17	Fyzabad . .	88·7	66·2	22·5	77·5	15·52	4·35	1,127·0	72	259·4	44·5	..
18	Shahjahanpur .	89·1	65·3	23·8	77·2	14·55	4·51	916·2	69	203·1	36·5	475

APPENDIX II—*contd*

	Stations	Temperature				Vapour pressure mm.	Absolute saturation deficit mm.	Yearly rainfall mm.	Humidity per cent	Meyer's N.S.Q.	Lang's R.F.	Elevation in feet above mean sea-level
		Mean max. °F.	Mean min. °F.	Diurnal difference	Average °F.							
	Padrauna	87·7	66·7	21·0	77·2	16·26	4·07	1,335·0	75	328·0	53·2	260
	Orai	91·2	69·0	22·2	80·1	13·44	5·64	918·7	58	162·8	34·4	.
	Sabour	86·3	65·6	20·7	76·0	16·87	3·71	1,218·0	78	328·1	49·9	..
	Ranchi	84·2	65·5	18·7	74·9	13·44	4·57	1,455·7	66	318·5	61·3	2,150
	Patna	87·3	68·6	18·7	78·0	16·66	4·67	1,233·0	72	264·2	48·2	183
	Nagpur	92·0	68·8	23·2	80·4	13·49	5·53	1,244·0	59	225·0	46·2	1,025
	Akola	93·2	67·4	26·8	80·3	12·83	5·64	796·3	56	141·1	20·7	930
	Wara Seoni	87·6	64·6	23·0	76·1	12·60	4·91	1,352·0	61	275·2	55·2	600
	Labhandi	90·2	67·5	22·7	78·9	14·33	5·44	1,292·1	62	237·5	49·5	..
	Chandkhuri	90·2	67·5	22·7	78·9	14·33	5·44	1,339·8	62	246·3	51·3	..
	Kheri-Adhartal	88·4	63·8	24·6	76·1	13·13	4·60	1,400·0	65	304·6	57·1	1,300
	Poarkhera	90·3	65·5	24·8	77·9	12·78	5·24	1,240·0	59	236·8	48·6	980
	Indore	88·2	63·9	24·3	76·1	13·23	5·03	841·2	62	167·3	34·3	1,823
	Kharna	88·8	64·5	24·3	76·7	12·57	5·28	791·4	58	149·9	31·9	1,700
	Makrera	88·5	65·2	23·3	76·8	12·52	4·76	498·6	62	104·8	20·0	1,700
	Tabiji	88·5	65·2	23·3	76·8	12·52	4·76	524·5	62	110·2	21·1	1,500
	Jorhat	81·3	65·7	15·6	73·5	17·53	1·40	2,416·0	92	1,725·7	104·6	250
	Karimganj	86·1	67·5	18·6	76·8	18·39	2·39	3,160·2	87	1,322·3	126·9	100
	Sylhet	86·1	67·5	18·6	76·8	18·29	2·38	2,835·8	87	1,191·5	113·9	90
	Dacca	86·2	70·5	15·7	78·4	19·53	3·71	2,148·8	81	579·2	83·3	22
	Rangpur	86·0	66·9	19·1	76·5	17·63	3·00	2,084·3	83	694·8	84·4	125
	Chinsura	87·8	70·6	17·2	79·2	18·85	3·58	1,539·7	81	430·1	58·8	50
	Dharwar	84·6	64·1	20·5	74·4	13·72	3·98	1,117·0	71	287·2	47·5	.
	Sholapur	91·4	68·3	23·1	79·9	12·67	5·70	722·6	55	126·4	27·2	1,590
	Sirsi	85·0	70·0	15·0	77·5	13·72	3·43	3,051·0	75	886·9	120·6	2,000
	Nadiad	94·6	70·6	24·0	82·6	14·66	5·72	905·5	61	158·4	32·2	..
	Bijapur	90·6	67·8	22·8	79·2	12·70	5·33	530·8	58	99·6	20·3	..
	Belgaum	84·6	64·1	20·5	74·4	13·97	4·75	1,016·0	66	213·9	43·2	2,550
	Kumta	86·1	72·7	13·4	76·4	19·18	3·07	3,048·0	84	993·2	123·4	..
	Padegaon	90·6	67·8	22·8	79·2	13·72	4·80	657·6	65	137·0	25·1	1,000
	Surat	91·5	69·9	21·6	80·7	17·14	5·14	1,041·0	70	202·4	38·4	36
	Coimbatore	89·9	69·7	20·2	79·8	18·39	3·49	566·2	70	162·8	21·3	1,348
	Taliparamba	87·7	74·4	13·3	81·1	20·45	4·09	3,118·2	80	762·4	114·2	600
	Koilpatti	93·7	74·2	19·5	84·0	19·05	5·52	852·9	71	154·4	29·5	400
	Aduturai	90·2	76·2	14·0	83·2	20·73	4·97	1,396·0	76	280·7	49·2	..
	Hagari	93·3	70·9	22·4	82·1	14·63	5·71	521·0	61	91·2	18·7	1,400
	Nandyal	93·8	71·2	22·6	82·5	16·20	5·19	660·7	68	127·3	23·5	900
	Samalkot	89·3	75·0	14·3	82·2	20·24	4·45	992·9	78	223·0	35·6	30
	Anakapalle	87·0	75·4	11·6	81·2	19·15	5·17	942·1	73	182·2	34·5	150
	Berhampur	86·1	73·3	12·8	79·7	19·94	3·79	1,142·0	81	301·5	43·1	80
	Pusa	87·1	66·5	20·6	76·8	16·10	5·67	1,178·6	71	207·9	47·3	164
	Delhi	89·2	64·8	24·4	77·0	13·13	5·51	681·7	58	123·6	27·3	718

Appendix III

Profile descriptions, as seen in the field (virgin soil)

(Samples collected foot-wise)

Profile No.	Station	Depth of horizon	Characteristics
		(in.)	
1	Peshawar (Tarnab Farm)	0—48	Greyish pink soil
		48—60	Greyish pink soil but sandy
2	Haripur (Hazara)	0—12	Light brownish grey
		12—60	Greyish brown
3	Lahore	0—60	Light greyish brown
7	Gurdaspur	0—12	Dark greyish brown
		12—36	Brownish
		36—60	Brownish but more clayey
8	Kangra	0—24	Light blackish brown, bits of boulders
		24—36	Light brown, about 30 per cent boulders
		36—48	Light brown, about 25 per cent boulders fine sandy
		48—60	Light brown, about 25 per cent boulders and *kankar* coarse sandy Boulders of various sizes
9	Lyallpur	0—60	Light pinkish grey
10	Mianwali	0—36	Greyish pink
		36—48	Greyish pink *kankar* present
		48—60	Greyish pink few bits of *kankar*
11	Sakrand	0—12	Light grey
		12—48	Light grey more sandy
		48—60	Light grey more sandy feels salty
12	Karachi (Malir Farm)	0—36	Light brownish with pink tinge
		36—60	Dark brownish with red tinge
13	Mirpurkhas	0—36	Greyish brown
		36—48	Blackish and hard (compacted)
		48—60	Black and harder
18	Shahjahanpur	0—12	Dark brownish grey
		12—60	Light brown
			The first foot contains a very small quantity of *kankar* (0·1 per cent) which do not effervesce with dilute hydrochloric acid
19	Padrauna (Low land)	0—12	Dark blackish with brown tinge
		12—24	Light grey
		24—48	Light grey more sandy, lime *kankar*
		48—60	Light grey more sandy
22	Ranchi (Upland)	0—24	Dark red with brown tinge
		24—36	Less red
		36—60	Less red but more heavy
24	Nagpur (Morand)	0—12	Brownish black with white specks
		12—24	Brownish black a few pieces of lime *kankar*
		24—60	Brownish black, *kankar* increasing with depth
25	Akola (Morand).	0—60	Uniformly black with brown tinge. *Kankar* present throughout the profile, amount increasing with depth

APPENDIX III—*contd*

Profile No.	Station	Depth of horizon	Characteristics
		(in.)	
26	Wara Seoni (Sihar).	0—24	Slightly greyish yellow
		24—36	Murrum
		36—60	Soil mixed with stones
27	Labhandi (Kanahar).	0—36	Black with brown tinge, small *kankars*
		36—60	Black with brown tinge, *kankar* in greater amounts
28	Chandkhuri (Bhata).	0—5	Dark brownish red, *kankar*
		5—15	Red, more *kankar*
		16—28	Dark red, still more *kankar*
		28—60	Red *kankar* size larger
29	Kheri-Adhartal (Kabar).	0—24	Light black, brown tinge, lime *kankar*
		24—36	Grey, lime *kankar*
		36—60	Brownish, lime *kankar*
30	Powarkhera (Mariyar).	0—36	Greyish black with brown tinge, lime *kankar*
		36—60	Dark grey with brown tinge, *kankar* diminishing with depth
31	Indore	0—36	Light black, lime *kankar*
		36—60	Brown, *kankar* increasing with depth
32	Kharua (Kali).	0—36	Slightly brownish black, lime *kankars*
		36—48	Greyish, lime *kankars*
		48—60	Whitish, *kankar* increasing
33	Makrera	0—36	Brownish grey
		36—48	Murrum, limey
		48—60	Fine sand, limey
34	Tabiji	0—36	Brown
		36—48	Slightly black
		48—60	Sandy
35	Jorhat (High land).	0—12	Dark reddish brown with yellow tinge
		12—24	Greyish yellow
		24—36	Yellow
		36—60	Deep yellow
36	Karimganj	0—12	Slightly blackish brown, forms stiff clods on drying
		12—60	Yellowish brown, ferruginous nodules
37	Sylhet	0—12	Blackish brown
		12—60	Yellowish brown, gets more clayey with depth
38	Dacca	0—12	Light brown with yellow tinge
		12—60	Ochrey red, richer in colour with depth
39	Rangpur	0—12	Slightly brownish black
		12—24	Blackish brown
		24—48	Sand
		48—60	Highly sandy soil
40	Chinsura	0—12	Deep greyish brown, hard and gritty when dry
		12—60	Brown with blackish tinge
43	Sirsi	0—12	Dark greyish red
		12—24	Red, with decomposed rock
		24—36	Deeper red, with decomposed rock
		36—48	Red, gravels and undecomposed black iron nodules
		48—60	Red, disintegrated rock, more black iron

APPENDIX III—*concld*

Profile No.	Station	Depth of horizon	Characteristics
		(in.)	
48	Padegaon	0—48	Black with slight pink tinge
		48—60	Greyish black, lime accumulation
49	Surat	0—12	Brownish black
		12—36	Black
		36—60	Blackish brown
50	Coimbatore	0—24	Deep red black
		24—42	Deep red black, *kankar*
		42—54	Pale coloured, *kankar* smaller size
51	Taliparamba (Wet land).	0—12	Blackish red
		12—24	Light reddish black
		24—60	Reddish brown
52	Koilpatti (Typical gypseous).	0—5	Mouse grey, loose granular
		5—12	Mouse grey, nodular, imbedded *kankar*
		12—24	Deep mouse-grey, prismatic, bigger *kankar* bits. A few gypsum particles
		24—36	Less deep mouse-grey, granular, both lime *kankar* and larger gypsum particles
		36—48	Mouse-grey, *kankar* size $\frac{1}{2}$ in. to $\frac{3}{4}$ in. diam., gypsum in flakes
		48—60	Dark olive grey, gypsum blocks, *kankar*
54	Hagari	0—12	Greyish black
		12—24	Greyish black, *kankar* bits
		26—36	Greyish, slight foliation, some gypsum
		36—48	Greyish brown, some gypsum
		48—60	Brownish
55	Nandyal	0—60	Blackish grey, no marked difference between layers
56	Samalkot	0—36	Light black with brownish tinge
		36 & below.	Water table
57	Anakapalle	0—12	Dark greyish red
		12—48	Greyish red
		48—60	Light greyish red
58	Berhampur	0—12	Greyish black
		12—24	Whitish grey
		24—36	Light brown
		36—48	Very light brown
		48—54	Whitish brown
		54 & below.	Red gravels
59	Pusa	0—12	Greyish brown
		12—60	Whitish brown interspersed with lime *kankar*
60	Delhi	0—12	Light brown
		12—24	Slightly darker brown. Compaction at 22 in. and below
		24—36	Dark brownish grey. More compacted
		36—48	Dark grey with slight brown tinge. Heavier and more compacted
		48—60	Light brownish grey. White streaks and white incrustated cavities at 55 in. Lime nodules at 58 in. Less compacted

COMPARATIVE STUDIES ON INDIAN SOILS

II. THE COMPOSITION OF CLAYS FROM SOIL PROFILES

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The complex alumino-silicates of the mineral part of the soil constitute is what is commonly known as clay or clay colloids or clay complex. The clay complex is the ultimate product of weathering and is derived from the rock minerals. The clay is the most reactive portion of the soil and by virtue of its powers of absorption and ionic exchange capacity it controls the chemical and physical properties of the soil besides holding all the important elements of plant nutrition. A chemical analysis of the whole soil can indicate only the gross composition of the weathered and unweathered materials of the soil and of the extent of the reserves of plant nutrients contained in the soil. Such an analysis, however, does not indicate chemical reactions and the trend of soil processes in the soil profile, as clearly as the analysis of the clay fractions does. The clay fractions of soils from the different horizons of the several profiles described in part I of this series of papers, were separated and analysed.

Separation of clays from soils

Attempts were at first made to separate the clay fractions by means of Sharple's Super-Centrifuge, but that proved time-consuming. The separations were, therefore, made by sedimentation method, as is done in the mechanical analysis of soils. Two years later, we noticed that Kelley, Dore *et al.* [1939] in California also employed the sedimentation method for their studies on the colloidal constituents of California soils. The following is the method employed by us for the separation of clay: The soils after rubbing with a wooden mallet and separation from gravel and *kankar*, etc. was passed through 2 mm. sieve. That which passed through the sieve was taken for the separation of clay. 500 c.c. of distilled water was added to every 25 gm. lots of soil and boiled for 15 minutes. After cooling the suspension was vigorously shaken by hand after adding 25 c.c. of ammonia (4 : 1) as a dispersing agent. This was then made up to 2,500 c.c. and transferred to a glass vessel of a size sufficient to give 10 cm. depth of supernatant suspension. At the end of 24 hours, the supernatant suspension of clay was siphoned off. Then the residue was rubbed with a rubber-tipped glass rod, made up with distilled water to a height of 10 cm., allowed to settle for 24 hours when the supernatant clay suspension was drawn off and added to the previous lot. This process was repeated till the supernatant liquid was almost free from suspended clay particles. Four or five successive pourings usually give a fairly clear supernatant liquid. These pourings were mixed and then boiled to coagulate the clay suspension. On settling of the clay the clear supernatant liquid containing any soluble salts was thrown away. After drying the creamy material first at 95-100°C. and then at 105°C., the clay samples were powdered and stored for analysis.

The following methods of analysis were adopted —2 gm. of clay, after determining hygroscopic moisture at 107-8°C., was subjected to digestion by Triacid mixture [Hardy, 1931; 1932]. This was then transferred to a beaker or a conical flask with 10 per cent HCl and digested on a bath for about four hours and filtered.

The residue was dried, ignited and weighed as sand. It was then transferred to a beaker, digested with 1 per cent NaOH for about an hour on a boiling water-bath with constant stirring, filtered and residue of quartz washed free of alkali with cold 10 per cent alcohol. Ignited and weighed. The difference between the sand and quartz gives the amount of soluble silicates.

The usual analytical procedures of the A.O.A.C. were adopted for the determination of alumina, iron oxide and lime. The filtrate from lime was evaporated down to dryness and ammonium salts were removed by ignition. The residue was digested with 10 per cent hydrochloric acid on a water bath for about half an hour and filtered. A convenient volume was made up of the filtrate and divided into two portions. In one portion the magnesium was determined as the pyrophosphate and the other portion was used for the determination of mixed chlorides of magnesium

potassium and sodium. The residue of triple chlorides was then taken up with hot water and potassium was determined by the Lindo-Gladding method. Sodium was obtained from the mixed chlorides after deducting the calculated amounts of magnesium and potassium obtained previously.

Analytical results are presented in Appendix.

Soil type and composition of clay

The analytical data on clays have been grouped according to climate into the four main zonal types of soils, namely arid, semi-arid, humid and per-humid and according to colour classification in vogue. Soils with calcium carbonate content of 10 per cent and over have been grouped separately as calcareous type of soils and separate from the major climatic or colour types but occurring within the major types.

Type—Arid soils. The average composition of the clays for the profile of the arid type of soils works out as shown in Table I.

Table I

Average composition of clay in the arid type of soil profile

Depth (in ft.)	Total SiO_2	Quartz	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
0—1	49·70	12·01	37·69	9·41	21·80	2·34	2·39	4·03	4·22
1—2	49·93	10·07	39·86	10·47	22·56	1·93	2·42	3·89	4·32
2—3	50·65	11·06	39·59	10·29	22·38	1·73	2·16	3·26	3·80
3—4	50·96	12·04	38·92	10·08	21·76	1·80	2·44	3·33	4·31
4—5	51·43	14·62	36·81	10·44	20·90	1·81	2·35	3·60	4·41

Average analytical values—molecular per cent

Depth (in ft.)	Per cent clay in soil	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
0—1	15·20	0·628	0·059	0·214	*0·042*	0·058	0·043	0·068
1—2	18·14	*0·664*	*0·666*	*0·221*	0·034	0·060	0·042	0·070
2—3	20·46	0·659	0·065	0·220	0·031	0·054	0·035	0·061
3—4	24·86	0·648	0·063	0·213	0·032	0·061	0·036	0·070
4—5	24·01	0·613	0·066	0·205	0·032	0·058	0·038	0·071

There is a tendency towards a lowering in the amounts of combined silica, iron oxide and alumina in the topmost layer and an accumulation in the second layer. A gradual falling off of the values with depth is noticeable afterwards, except for a slight rise in value of iron oxide in the last depth. The highest content of lime, as would be expected under the climatic conditions, is found in the first depth remaining practically unchanged throughout in the lower depths. Same is true for potash, which is rather high due probably to the presence of undecomposed feldspars. Magnesia and soda are found to remain practically constant throughout the profile. Lime and soda are slightly in excess over magnesia and potash and the monovalent bases are present in higher proportions than the divalent bases indicating conditions of salinity. The analytical values as well as the clay content of the soil from different depths show slight increase of finer particles down the profile.

Table II

Derived and property values

Depth (in ft.)	Weathering per cent	Combined $\frac{SiO_2}{R_2O_3}$	Combined $\frac{SiO_2}{Fe_2O_3}$	Combined $\frac{SiO_2}{Al_2O_3}$	Combined $\frac{SiO_2}{Bases}$	$\frac{Al_2O_3}{Fe_2O_3}$	Saturation (Ex. bases) per cent	*p*H antimony electrode
0—1	75·8	2·31	10·74	2·95	3·09	3·65	96·1	7·35
1—2	80·0	2·33	10·50	3·03	3·40	3·50	94·8	7·33
2—3	78·7	2·34	10·53	3·03	4·27	3·47	98·0	7·23
3—4	76·7	2·37	10·62	3·08	3·67	3·47	96·3	7·26
4—5	72·0	2·30	10·25	3·06	3·45	3·50	98·5	7·31

Table II shows the constancy of composition of the clay minerals in all the depths, the only exception being the base contents which have accumulated at the surface probably by capillary rise as is indicated by the gradual increase in SiO_2/ base values. The clay of the last depth is more quartzose than those from the upper layers. Under the high prevailing temperature of 24·2°C. and a scanty and precarious rainfall of 11·4 in. per annum only a moderate degree of disintegration and a high accumulation of salts has taken place. The SiO_2/Al_2O_3 ratio of 3·03 shows that the colloid complex has probably a constitution intermediate between kaolinite and pyrophyllite, almost as a constant composition

mixture. The Al_2O_3/Fe_2O_3 ratio down the profiles is constant.

The arid type of soils have a pink, greyish pink or brownish pink colour due probably to the syenitic rocks in these regions. The average composition of clays of these profiles is given in Table III.

Table III

Average composition of clay in the profiles of pink coloured soils

Depth (in ft.)	Total SiO_2	Quartz	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
0—1	49·77	11·27	38·50	10·87	21·75	1·81	2·20	3·43	3·46
1—2	50·01	11·19	38·82	10·63	24·01	1·30	2·02	3·51	3·28
2—3	50·17	12·22	37·95	10·06	24·24	1·33	1·68	3·28	2·74
3—4	49·20	12·31	36·89	10·05	23·81	2·61	1·83	3·03	2·77
4—5	49·18	14·99	34·19	9·46	23·07	3·30	1·90	2·93	3·22

The average sesquioxide ratios for the surface soils in the two types of classification are as below :

	Combined SiO_2/R_2O_3	Combined SiO_2/Al_2O_3
Arid type . .	2·31 ± 0·18	2·95 ± 0·22
Pinkish type . .	2·13 ± 0·58	2·81 ± 0·57

Type—Semi-arid soils. The detailed analytical data for the clays of the semi-arid type of soil profiles are given in statement in the appendix. The average composition is given in Table IV.

Table IV

Average composition of clays—semi-arid type of profile

Depth (in ft.)	Total SiO_2	Quartz	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
0—1	50·96	7·16	43·80	11·31	22·01	2·24	2·12	1·91	3·17
1—2	51·37	6·85	44·52	11·64	23·10	2·00	2·10	2·02	3·15
2—3	50·31	6·30	44·01	11·31	23·20	2·02	1·96	1·91	3·20
3—4	50·33	6·03	44·30	11·33	22·70	2·71	1·90	1·84	3·35
4—5	49·09	7·35	41·74	11·04	21·41	3·81	1·98	1·92	3·59

Average analytical values—molecular per cent

Depth (in ft.)	Per cent clay in soil	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
0—1	36·85	0·729	0·071	0·216	0·040	0·053	0·020	0·051
1—2	40·42	*0·741*	*0·073*	0·227	0·036	0·052	0·021	0·051
2—3	43·40	0·735	0·071	*0·228*	0·036	0·049	0·019	0·052
3—4	41·87	0·741	0·071	0·223	*0·049*	0·047	0·019	0·054
4—5	40·33	0·695	0·069	0·211	0·068	0·049	0·020	0·058

It will be noticed from Table IV that as in the case of arid type soils, the constituents in the top layer are less than those in the next one below. The composition of the colloidal complex in the second, third and fourth layers has practically the same values. These three depths might thus be considered to be one horizon of the profile and with an average composition which works out as follows : 1-4 ft., 40·90, 0·739, 0·072, 0·226, 0·040, 0·049, 0·020, 0·052 and may thus be termed the illuvial layer. The fourth and fifth depths show the characteristic process of Marbut's Pedocal formation, where the calcium is converted to calcium carbonate and is then deposited as such at that depth. Calcium is solubilized as bicarbonate by carbon dioxide from organic decomposition, and its percolation to greater depths is not allowed by the low rainfall (27·8 in.) of this region and hence a deposit is formed at a depth to which the rain waters penetrate. Calcium-bearing materials can also rise from lower depths in the capillary water due to very high prevailing temperature (26·1°C.) of this region and are precipitated in the zone of calcification.

As in the case of arid soils lime plus soda is in excess over magnesia plus potash but divalent bases are in excess over the monovalent bases.

The major constituents are present in higher amounts in the semi-arid type of soils than in the arid type showing a greater degree of decomposition. The bases are present in lower amounts owing to a higher precipitation. CaO increases with depth here against a decrease in the arid type. Na_2O also shows a slight increase with depth, while magnesia shows decrease. K_2O is practically constant possibly as undecomposed feldspar. Except in the case of CaO the variations found are very small indeed and the colloids developed in this series show a singular uniformity

of composition. The relatively high values for MgO, Na_2O and K_2O indicate either the presence of minerals resistant to hydrolysis or that the colloid complex has a very strong affinity for these bases. A tendency towards increase in the clay colloids is shown here also (Table V) as in the case of arid soils.

TABLE V

Derived and property values

Depth (in ft.)	Weathering per cent	Combined SiO_2/R_2O_3	Combined SiO_2/Fe_2O_3	Combined SiO_2/Al_2O_3	Combined SiO_2/bases	Al_2O_3/Fe_2O_3	Saturation (Ex. bases) per cent	pH (Sb.)
0—1	86·0	2·53	10·65	3·40	5·34	3·18	96·8	7·72
1—2	86·8	2·50	10·70	3·31	5·54	3·26	95·3	7·63
2—3	87·6	2·51	10·88	3·29	5·28	3·35	95·0	7·57
3—4	87·9	2·56	10·92	3·37	5·09	3·25	96·3	7·19
4—5	84·8	2·53	10·58	3·37	4·27	3·15	96·3	7·76

Most of the above ratios for clays of this series are higher than those of the arid series excepting for a lower ratio Al_2O_3/Fe_2O_3 indicating the presence of a proportionately higher amount of iron oxide in the complex than alumina. Accumulation of calcium carbonate is reflected in the lower SiO_2/base ratios in the fourth and fifth layers. A loss of SiO_2 and Fe_2O_3 is indicated by the ratios SiO_2/R_2O_3 and SiO_2/Fe_2O_3 and points to the trend of the weathering processes. The small variations in the SiO_2/R_2O_3 values, when considered by themselves, show a constancy of composition of the major constituents throughout the profile, but the SiO_2/Fe_2O_3 and SiO_2/Al_2O_3 ratios show that there is an accumulation of Al_2O_3 with depth up to the third foot depth and then falls away and the ratio becomes constant; whereas Fe_2O_3 leaves the complex up to the fourth foot depth and is showing accumulation in the last or fifth foot depth indicating downward movement. The clay of the fifth foot is found to be more quartzose than the preceding layers, as was found with arid soils.

The mean value of 3·35 for SiO_2/Al_2O_3 suggests that the colloidal complex is composed of either (i) a mixture of kaolinite, Al_2O_3, 2 SiO_2, 2 H_2O and montmorillonite Al_2O_3, 4 SiO_2, H_2O, nH_2O the latter being in excess, or (ii) a mixture of Biedellite, Al_2O_3, 3 SiO_2, H_2O, nH_2O and montmorillonite, the former being in excess.

Type—Humid soils. The detailed analytical data for clays of the humid type of soil profiles are given in the statement in appendix. The average profile clay composition is given in Table VI.

TABLE VI

Average compositions of clays—humid type of profile.

Depth (in ft.)	Total SiO_2	Quartz	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
0—1	50·17	9·26	40·91	11·99	24·17	1·15	1·12	2·35	1·89
1—2	48·77	6·39	42·38	11·98	26·83	1·16	1·08	2·30	2·07
2—3	48·83	6·11	42·72	12·02	26·58	1·00	1·04	2·48	2·32
3—4	48·64	6·10	42·54	12·52	26·45	1·14	1·22	2·12	2·05
4—5	49·47	7·65	41·82	12·33	25·39	1·21	1·26	2·03	2·33

Average analytical values—molecular per cent

Depth (in ft.)	Per cent clay in soil	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
0—1	37·76	0·681	0·075	0·236	0·021	0·028	0·025	0·030
1—2	44·67	0·705	0·075	*0·263*	0·021	0·027	0·025	0·034
2—3	45·07	*0·711*	0·075	0·261	0·018	0·026	0·026	0·034
3—4	42·70	0·708	*0·078*	0·260	0·020	0·030	0·023	0·033
4—5	43·72	0·697	0·077	0·249	0·022	0·031	0·022	0·037

The table of molecular values shows the remarkable constancy in composition of the clay colloids of the second, third and fourth depths, the only departure being a very slight increase in the Fe_2O_3 and MgO content in the fourth depth suggesting their derivation from a common source or similar reactions. If the three depths are considered to be parts of the same horizon the following figures will indicate the analytical values for the clay of that horizon: 1-4 ft., 44·15, 0·708, 0·076, 0·261, 0·020, 0·028, 0·025, 0·034, showing an accumulation of silica, alumina and iron oxide in this horizon, the former two extensively. The bases show no change from their contents of the surface soil with the exception of a slight accumulation of soda. The clay content is also higher. A high degree of translocation of the fine colloids to these depths is indicated. The lower values for clay

silica, and sesquioxides in the first depth point to their eluviation to lower depths owing to heavier rainfall in this region. The base content is much lower, $CaO + Na_2O$ is balanced by $MgO + K_2O$ in all the depths. $MgO + Na_2O$ is in excess over $CaO + Na_2O$ (pointing to a micaceous clay) and the value increases with depth. R_2O is slightly predominating over RO.

TABLE VII

Derived and property values

Depth (in ft.)	Weathering per cent	Combined SiO_2/R_2O_3	Combined SiO_2/Fe_2O_3	Combined SiO_2/Al_2O_3	Combined SiO_2/bases	Al_2O_3/Fe_2O_3	Saturation (Ex. bases) per cent	pH (Sh.)
0—1	81·8	2·20	9·23	2·91	7·06	3·20	93·4	6·84
1—2	87·2	2·12	9·65	2·73	6·96	3·59	93·5	7·10
2—3	87·7	2·15	9·68	2·78	6·95	3·53	94·2	7·40
3—4	87·6	2·14	9·28	2·80	7·14	3·39	94·1	7·36
4—5	85·3	2·16	9·31	2·84	6·64	3·37	96·6	7·38

The figures in Table VII show that more silica is solubilized and is present in depths 2, 3 and 4 than what was present in the surface layer. Translocation of sesquioxides has also taken place as shown by SiO_2/R_2O_3 values, the maximum accumulation of alumina being in second depth and of ferric oxide in the fourth depth. In the upper layers the mobility of Fe_2O_3 is more than that of Al_2O_3. The gradual increase of SiO_2/Al_2O_3 values shows that alumina is leaving the complex while SiO_2/Fe_2O_3 values in the lower depths show an accumulation of Fe_2O_3 probably in the form of free oxide.

The eluviation of finer colloids, silica and sesquioxides is due to a break down of the clay complex and products subsequently becoming more mobile show the process of typical tropical weathering.

The silica/base ratio is practically the same except in the last depth where it is somewhat high due to a slight accumulation, as well as to a leaching away of silica owing to a definitely higher amount of precipitation of 50 in. annual rainfall. The saturation of the clay with exchangeable bases is somewhat lowered owing to the partial hydrogenation of the clay due to hydrolysis under definitely humid and hot conditions. This is also reflected in the pH value the lowest 6·84 being shown by the surface layer. The value gradually rises to 7·40 in the third layer and remains alkaline without further change—this has probably a connection with the higher Na_2O content in the lower depths.

As in previous cases, the clay in the last depth is more quartzose than the previous three depths but less so than the surface layer where the action of decomposition is most intense.

The humid soils are developed under an average annual rainfall of 49·6 in. and a mean annual temperature of 25·7°C. The surface layer is silty clay and the lower layers are clay loam.

The average value of 2·81 for SiO_2/Al_2O_3 points to the colloid being a mixture of Kaolinite and Pyrophyllite (Al_2O_3, 4 SiO_2, 3 H_2O), the former predominating.

In the semi-arid and humid zones occur black, brown and red soils, derived from almost all types of rock systems. These are not always residues which have survived weathering processes but are also transported soils with adsorption complexes of iron oxides and silicates. Those produced from lime stones are naturally rich in lime content and are more alkaline in reaction, e.g. Surat soil developed from Nummulites and Tabiji soil derived from igneous lime stones. These soils contain a proportionately higher amount of silicic acid which is due to the removal of the bases of the alkali and alkaline earth metals. An enrichment in both Fe_2O_3 and Al_2O_3 is also noticed.

The black soils are produced from decomposition of basalts gneisses and granites mostly in the semi-arid region. These soils are highly siliceous and contain somewhat lower amounts of sesquioxides than the brown soils. The average composition of clay from black soil profile is given in Table VIII.

TABLE VIII

Average composition of clay—black soils

Depth (in ft.)	Total SiO_2	Quartz	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
0—1	52·30	5·94	46·36	11·04	22·67	2·26	2·16	1·50	2·36
1—2	52·96	6·28	46·68	11·38	22·79	2·22	1·99	1·44	2·88
2—3	51·81	5·86	45·95	11·30	22·44	2·06	2·04	1·46	2·83
3—4	52·21	5·46	46·75	11·41	22·33	2·30	2·09	1·37	2·93
4—5	51·17	6·69	44·48	11·20	21·43	3·20	2·01	1·36	2·94

TABLE IX

Type—per-humid soils

Average composition of clays—per-humid type of profile

Depth (in ft.)	Total SiO_2	Quartz	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
0—1	44·03	7·48	36·55	10·27	28·19	0·44	1·34	2·14	1·68
1—2	45·74	9·31	36·43	9·99	29·56	0·36	1·08	2·45	1·65
2—3	46·11	9·78	36·33	9·91	29·47	0·34	1·06	2·33	1·44
3—4	46·97	10·76	36·21	9·89	29·73	0·33	0·91	2·15	1·58
4—5	47·21	11·33	35·88	10·67	29·97	0·34	0·90	2·03	1·76

Average analytical values—molecular per cent

Depth (in ft.)	Per cent clay in soil	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
0—1	15·52	0·564	0·064	0·277	0·008	0·033	0·023	0·027
1—2	23·87	0·607	0·063	0·290	0·006	0·028	0·026	0·027
2—3	26·77	0·592	0·062	0·289	0·006	0·026	0·025	0·023
3—4	30·15	0·603	0·062	0·202	0·006	0·023	0·023	0·027
4—5	24·03	0·598	0·067	0·294	0·006	0·022	0·022	0·028

The most notable feature in Table IX is the constancy of composition of the colloid, specially in the depths 2, 3 and 4. Leaching away of silica with consequent accumulation of iron oxide and alumina is shown by both the first and the fifth layers. The figures for Al_2O_3, Fe_2O_3 and SiO_2 all show a downward movement of the colloidal complex. This is also shown by the finer fraction of the soil—the clay. All the bases, with the exception of CaO are present in moderately high amounts, probably due to the entry of these bases, at least some, into the clay lattice by the replacement of H^+ ions of the hydrogen clay produced under the moderately heavy average annual rainfall of 98 in. This appears to be the most important soil-forming process in this region.

All the bases show a higher accumulation in the upper layers than in the lower ones. R_2O preponderates over RO and $MgO + K_2O$ and $MgO + Na_2O$ are in higher amounts than $CaO + Na_2O$ and $CaO + K_2O$ respectively, pointing to the presence of micaceous bodies.

The highest amount of alumina is present in this type of soils, while both SiO_2 and Fe_2O_3 are present in much less amounts than in the humid or even in semi-arid type of soils. This shows the removal of these constituents from the complex under conditions of very high rainfall, 97·7 in. per annum and high average daily temperature of 24·4°C.

The leaching down of alumina without sufficient SiO_2 to the depths is conducive to the formation of kaolin beds.

TABLE X

Derived and property values

Depth (in ft.)	Weathering per cent	Combined SiO_2/R_2O_3	Combined SiO_2/Fe_2O_3	Combined SiO_2/Al_2O_3	Combined SiO_2/bases	Al_2O_3/Fe_2O_3	Saturation (Ex. bases) per cent	pH (Sb.)
0—1	83·3	1·66	9·29	2·04	7·88	4·51	57·1	5·21
1—2	81·6	1·73	10·18	2·11	8·96	4·87	47·2	5·04
2—3	78·7	1·67	10·30	2·03	8·81	4·99	45·3	5·01
3—4	79·5	1·69	11·00	2·06	10·07	5·31	48·1	5·01
4—5	77·8	1·64	10·50	2·01	9·40	5·08	49·3	5·06

The silica/sesquioxide and silica/alumina ratios show that the soil-forming process governing this region has brought about a definite decrease in these ratios. The SiO_2/Fe_2O_3 and Al_2O_3/Fe_2O_3 ratios show a slight degree of fractionation of the colloid. The figures for SiO_2/R_2O_3 and SiO_2/Al_2O_3 show that the soil-forming process has gone beyond the kaolinization stage and is proceeding towards the laterization process—the first stage of which is generally assumed to be kaolinization. The kaolinized product is first formed by silicate minerals undergoing hydrolysis, the alkaline solutions being removed away. Under conditions of high temperature, 24·4°C., and abundant moisture due to high rainfall, 97·7 in., this kaolin is further hydrolysed with separation and removal of silica to hydrated oxides of aluminium and iron. The figures for weathering show a distinct leaching away of soluble silica resulting into the complex getting more and more quartzose. The high degree of unsaturation of the exchange bases also point to the process of laterization. This stat

unsaturation is also reflected in the *p*H values owing quite definite acidity.

Sesquioxides are relatively high in proportion silica but have not yet reached the extreme roportions characteristic of true laterites. The ecreasing values for SiO_2/Al_2O_3 show an accu- ulation of Al_2O_3 in the different layers, the ghest being in the last depth. Higher values r SiO_2/bases in the lower layers show effective moval of bases, and decreasing values for per nt weathering show removal of soluble silica om the colloid complex.

The somewhat higher degree of saturation of xchange bases in the surface layer is probably ue to the comparatively high amount, 2 per cent soil, of organic matter present. Highest con- nt of organic matter is found with soils of this pe.

Most of the red soils including the so-called late- te soils are formed in the humid and per-humid gions. Brown soils occur in the humid region so. Some black coloured soils also occur in ese regions produced under swampy conditions. the humid and per-humid regions where high mperatures also prevail, a vigorous hydrolysis silica and sesquioxides takes place, and the sultant colloidal iron oxide complex is diffused roughout the soil and endow it with red colour. hese soils are not necessarily laterites in which ne silica is also leached out while in red soils lica accumulates. The average composition of ays from red and brown soils is shown in Table I.

TABLE XI

Depth (in ft.)	Total SiO_2	Quartz	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
Red soils									
–1	40·58	6·54	34·04	12·72	29·59	0·46	0·95	1·49	1·13
–2	40·80	3·26	37·54	12·65	32·74	0·26	0·94	1·68	1·38
–3	41·69	4·47	37·22	12·92	31·94	0·27	0·84	1·90	1·76
–4	42·46	4·89	37·57	12·79	32·62	0·25	0·76	1·65	1·69
–5	43·25	5·29	37·96	12·81	30·35	0·27	0·73	1·46	2·14

TABLE XI—*contd*

Depth (in ft.)	Total SiO_2	Quartz	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
Brown and reddish brown soils									
0—1	48·60	9·91	38·66	10·93	23·81	1·26	1·42	2·77	3·0
1—2	47·98	8·46	39·52	11·35	25·84	1·10	1·44	3·00	2·65
2—3	48·07	7·83	40·24	11·18	26·24	1·13	1·33	2·81	2·95
3—4	48·70	8·80	39·90	11·26	25·57	1·20	1·31	2·56	3·04
4—5	48·50	10·06	38·44	12·00	25·10	1·23	1·38	2·81	3·32
Calcareous soils									
0—1	45·84	13·58	32·26	9·67	19·39	5·46	3·65	3·52	4·16
1—2	48·26	15·75	32·51	9·28	18·70	6·69	2·59	3·74	3·39
2—3	46·76	15·37	31·39	9·14	17·69	8·43	2·84	3·65	3·29
3—4	46·40	16·12	30·28	8·40	15·49	10·05	2·60	4·13	3·57
4—5	48·93	18·15	30·78	8·19	16·90	9·03	2·04	3·71	4·14

The average silica-sesquioxide ratios for the surface soils are given in Table XII.

TABLE XII

	Combined SiO_2/R_2O_3	Combined SiO_2/Al_2O_3
Arid zone soils	2·31 ± 0·18	2·05 ± 0·22
Semi-arid zone soils	2·53 ± 0·39	3·40 ± 0·48
Humid zone soils	2·20 ± 0·37	2·91 ± 0·55
Per-humid zone soils	1·66 ± 0·34	2·04 ± 0·38
Pink and grey soils	2·13 ± 0·58	2·81 ± 0·57
Black soils	2·59 ± 0·35	3·40 ± 0·44
Brown and red brown soils	2·12 ± 0·50	2·81 ± 0·84
Red soils	1·56 ± 0·18	1·97 ± 0·25
Calcareous soils	2·15 ± 0·25	2·86 ± 0·37

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APPENDIX

CLIMATIC CLASSIFICATION

I. Soils of arid region

Analytical values—per cent on dry clay

Station	Depth (in ft.)	Quartz	Combined silica	Total silica	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
1. Mirpurkhas	0—1	12·45	37·84	50·29	9·23	23·51	2·69	0·80	3·45	2·71
2. Mianwali		11·27	38·14	49·41	8·15	20·36	2·42	4·01	3·93	2·94
3. Lyallpur		12·11	38·67	50·78	10·07	21·23	1·52	1·60	3·65	7·72
4. Haripur (Hazara)		12·21	36·10	48·31	10·19	22·08	2·73	3·13	5·10	3·52
1. Mirpurkhas	1—2	9·47	40·19	49·66	10·32	25·87	2·35	0·28	3·55	3·11
2. Mianwali		13·32	39·71	53·03	7·61	21·32	2·38	4·41	3·18	3·28
3. Lyallpur		11·57	38·41	49·98	12·66	19·39	1·46	1·46	3·39	7·25
4. Haripur (Hazara)		5·91	41·12	47·03	11·30	22·67	1·53	3·54	5·45	3·65
1. Mirpurkhas	2—3	9·76	40·88	50·64	10·49	25·57	1·33	0·41	1·42	2·47
2. Mianwali		13·99	39·22	53·21	7·67	20·20	3·00	3·69	3·26	1·72
3. Lyallpur		13·10	37·78	50·88	11·80	20·16	1·27	1·12	3·44	7·14
4. Haripur (Hazara)		7·40	40·48	47·88	11·18	23·58	1·33	3·43	4·90	3·89
1. Mirpurkhas	3—4	12·58	39·20	51·78	9·82	25·82	1·41	0·37	3·30	2·36
2. Mianwali		12·04	38·96	51·00	7·46	18·78	3·35	4·77	2·32	2·97
3. Lyallpur		17·53	36·15	53·68	11·87	19·16	1·18	1·24	3·12	7·02
4. Haripur (Hazara)		5·99	41·39	47·38	11·16	23·26	1·26	3·38	4·59	4·88
1. Mirpurkhas	4—5	13·52	38·84	52·36	10·82	25·12	1·68	0·25	3·02	2·79
2. Mianwali		20·45	31·04	51·49	5·44	18·77	3·21	4·42	2·99	4·32
3. Lyallpur		18·60	36·03	54·63	13·72	15·85	1·21	1·42	2·91	6·89
4. Haripur (Hazara)		5·92	41·34	47·26	11·79	23·87	1·24	3·32	5·49	3·65

II. Soils of semi-arid region

Analytical values—per cent on dry clay

Station	Depth (in ft.)	Total silica	Quartz	Combined silica	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
1. Hagari	0—1	53·08	3·36	49·72	10·40	22·02	2·75	0·37	0·83	3·76
2. Lahore		46·97	5·04	41·93	12·82	24·38	1·47	2·20	3·76	5·23
3. Tabiji		48·22	9·40	38·82	10·56	18·81	2·81	0·23	2·18	3·45
4. Makrera		53·06	20·06	33·00	10·44	18·65	1·86	3·78	3·17	2·89
5. Delhi		52·88	3·81	49·07	13·34	21·68	1·67	0·86	2·77	6·56
6. Nandyal		53·88	2·53	51·35	11·07	26·26	1·64	0·57	1·08	4·09
7. Padegaon		51·00	1·69	49·31	11·00	19·17	3·22	4·89	0·66	3·22
8. Kharua		51·00	8·03	42·97	8·70	20·09	4·09	3·46	2·18	1·65
9. Akola		53·53	8·10	45·43	11·52	20·66	1·94	3·42	1·20	3·95

II. Soils of semi-arid region—*contd*

Station	Depth (in ft.)	Total silica	Quartz	Combined silica	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
	0—1									
0. Koilpatti		55·24	5·45	49·79	7·79	22·08	2·28	4·71	0·92	2·86
1. Coimbatore		53·26	12·00	43·26	10·30	23·67	0·68	0·32	0·97	0·84
2. Indore		55·14	12·28	42·86	10·09	23·02	2·43	3·18	3·59	1·80
3. Anakapalle		44·19	3·32	40·87	16·08	21·79	1·12	2·25	2·16	2·25
4. Gurdaspur		43·12	8·95	34·17	11·14	23·68	2·71	0·37	2·59	4·77
5. Surat		47·84	3·42	44·42	14·45	24·21	2·87	1·12	0·66	0·17
	1—2									
1. Hagari		50·68	3·36	47·32	11·81	25·44	4·73	0·40	1·24	5·32
2. Lahore		47·82	5·07	42·75	13·24	24·87	1·07	2·10	3·40	4·05
3. Tabiji		50·06	14·45	35·61	7·53	24·28	3·23	0·26	4·98	2·24
4. Makrera		51·80	15·69	36·11	10·97	20·26	1·47	4·15	3·35	2·85
5. Delhi		49·60	3·86	45·74	13·64	23·09	1·22	0·88	3·03	4·86
6. Nandyal		52·38	3·54	48·84	11·63	26·19	1·68	0·65	1·14	4·75
7. Padegaon		51·02	1·63	49·39	10·95	19·56	3·00	4·80	1·00	4·10
8. Kharua		52·34	8·79	43·55	8·89	20·35	4·00	3·34	1·96	1·44
9. Akola		53·44	8·22	45·20	12·20	22·08	1·44	2·24	1·08	2·61
0. Koilpatti		56·39	8·26	48·13	7·71	21·08	2·09	4·60	0·97	3·20
1. Coimbatore		52·87	8·42	44·45	11·18	25·09	0·86	0·33	0·52	0·78
2. Indore		59·95	10·02	49·93	9·94	21·37	2·38	2·69	2·09	1·55
3. Anakapalle		45·37	2·79	42·58	15·92	22·91	1·01	2·16	2·24	2·20
4. Gurdaspur		45·87	5·24	40·63	12·91	28·10	0·75	0·36	2·59	4·24
5. Surat		50·95	3·41	47·54	16·15	21·86	1·08	1·34	0·65	3·00
	2—3									
1. Hagari		50·69	3·35	47·34	8·66	24·52	2·69	0·34	0·97	5·59
2. Lahore		47·91	5·49	42·42	11·27	27·72	0·95	0·71	4·95	3·45
3. Tabiji		47·85	8·87	38·95	9·60	24·51	3·02	0·37	2·01	3·08
4. Makrera		50·58	13·59	36·99	10·73	20·45	2·24	4·15	3·05	3·04
5. Delhi		49·76	3·82	45·94	13·37	23·63	1·87	0·39	2·97	4·76
6. Nandyal		51·50	2·80	48·70	11·13	25·90	1·35	0·90	1·02	4·29
7. Padegaon		52·22	1·66	50·56	11·42	18·47	2·91	5·03	0·47	3·66
8. Kharua		50·20	8·02	42·18	9·24	21·07	3·95	3·40	2·03	0·79
9. Akola		53·41	7·33	46·08	13·08	21·27	1·63	2·79	1·81	3·28
0. Koilpatti		55·17	8·73	46·44	6·80	20·38	3·17	4·21	0·94	3·08
1. Coimbatore		53·33	10·12	43·21	10·02	25·60	1·51	0·30	0·60	1·34
2. Indore		50·85	9·09	41·76	10·70	20·64	2·06	3·17	2·07	1·97
3. Anakapalle		44·61	2·90	41·71	15·76	22·94	1·23	2·12	2·31	2·28
4. Gurdaspur		46·17	5·93	40·24	11·67	28·64	0·77	0·48	2·58	5·02
5. Surat		50·39	2·73	47·66	16·16	22·22	0·94	1·08	0·80	2·36
	3—4									
1. Hagari		50·17	3·34	46·83	10·23	22·93	2·64	0·45	1·30	7·86
2. Lahore		49·42	6·98	42·44	12·18	26·16	0·85	0·71	4·16	4·16
3. Tabiji		50·66	10·25	40·41	10·12	23·40	2·44	0·49	2·44	4·06
4. Makrera		38·85	8·26	30·59	9·54	18·77	10·67	4·30	2·09	2·04
5. Delhi		52·14	5·48	46·66	14·18	21·79	1·85	0·59	2·92	4·24

II. Soils of semi-arid region—*concld*

Station	Depth (in ft.)	Total silica	Quartz	Combined silica	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
	3—4									
6. Nandyal		53·23	2·64	50·59	11·08	25·43	1·32	0·49	0·89	5·16
7. Padegaon		52·21	1·69	50·52	11·42	17·85	2·93	4·87	0·71	2·82
8. Kharua		51·49	8·04	43·45	9·17	22·15	4·11	3·25	2·01	2·38
9. Akola		52·91	6·26	46·65	12·46	22·56	1·69	2·02	1·45	2·26
10. Koilpatti		54·01	6·06	47·95	6·52	20·10	4·28	4·87	0·97	2·63
11. Coimbatore		53·43	11·38	42·05	9·55	21·43	3·00	0·26	0·65	1·47
12. Indore		52·21	8·46	43·75	10·41	23·07	2·26	3·22	3·16	2·06
13. Anakapalle		47·04	2·40	44·64	14·63	23·44	1·27	2·10	1·64	2·57
14. Gurdaspur		46·69	6·08	40·61	12·65	28·18	0·72	0·37	2·39	4·70
15. Surat		50·47	3·16	47·31	15·82	23·29	0·80	0·93	0·89	1·91
	4—5									
1. Hagari		50·19	4·44	45·75	12·41	24·50	2·00	0·40	1·23	6·13
2. Lahore		48·19	5·95	42·24	10·84	27·60	1·18	1·15	3·83	3·54
3. Tabiji		52·07	18·99	33·08	9·68	19·25	3·42	0·29	3·01	5·73
4. Makrera		39·85	16·54	23·31	8·20	13·70	14·85	4·64	1·70	2·18
5. Delhi		51·71	5·86	45·85	13·49	21·36	2·98	0·48	2·69	4·22
6. Nandyal		53·06	4·77	48·29	10·94	26·96	1·40	0·33	0·83	4·30
7. Padegaon		37·98	4·04	33·94	7·89	12·95	10·31	2·67	0·72	4·45
8. Kharua		50·38	8·03	42·30	8·50	21·19	5·53	3·48	2·06	1·54
9. Akola		51·50	3·72	47·78	13·00	20·84	1·99	2·61	1·52	2·87
10. Koilpatti		54·23	5·16	49·07	6·10	19·66	4·44	4·91	1·00	3·04
11. Coimbatore			..	..	..	..	..	..	..	..
12. Indore		53·85	12·04	41·81	11·11	21·40	2·05	2·73	2·74	2·13
13. Anakapalle		47·05	2·34	44·71	14·98	22·78	1·45	2·21	1·73	2·64
14. Gurdaspur		46·37	7·76	38·61	12·44	26·83	0·75	0·47	2·70	5·25
15. Surat		50·87	3·31	47·56	14·93	20·79	1·05	1·40	1·16	2·24

III. Soils of humid region

Analytical values—per cent on dry clay

Station	Depth (in ft.)	Total silica	Quartz	Combined silica	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
	0—1									
1. Shahjahanpur		54·19	22·42	31·77	10·97	19·70	0·92	2·34	4·32	2·06
2. Samalkot		50·89	2·71	48·18	11·10	24·06	0·97	0·55	2·60	2·48
3. Nagpur		50·03	5·01	45·02	13·81	24·00	1·29	0·36	1·15	1·53
4. Powarkhera		53·98	11·49	42·49	9·13	23·01	1·97	2·72	1·99	1·38
5. Labhandi		50·63	8·92	41·71	11·14	25·73	1·03	1·32	2·18	0·98
6. Chandkhuri		45·54	14·47	31·07	14·67	25·47	0·11	0·49	1·72	1·88
7. Wara Seoni		42·57	2·26	40·31	12·37	27·44	1·33	1·16	2·75	2·56
8. Berhampur		55·19	10·29	44·90	11·79	19·08	0·94	0·66	3·24	3·20
9. Kheri-Adhartal		51·99	7·26	44·73	13·47	23·46	1·72	0·60	1·18	1·38
10. Ranchi		47·04	9·51	37·53	11·63	28·67	1·37	1·34	2·21	0·94
11. Chinsura		49·90	7·56	42·34	11·86	25·29	1·04	0·74	2·51	2·20

III. Soils of humid region—*contd*

Station	Depth (in ft.).	Total silica	Quartz.	Combined silica	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
1. Shahjahanpur	1—2	46·12	7·60	38·52	12·87	29·27	0·68	2·29	4·10	1·51
2. Samalkot		50·74	2·51	48·23	11·11	24·50	0·94	0·42	3·00	3·89
3. Nagpur		51·12	3·63	47·49	13·83	22·97	1·77	0·60	1·47	3·03
4. Powarkhera		56·23	16·10	40·13	8·87	22·77	2·03	2·31	1·67	0·74
5. Labhandi		52·01	9·98	42·03	10·62	26·89	1·43	1·52	2·27	1·86
6. Chandkhuri		40·98	5·02	35·96	15·69	29·64	0·23	0·59	2·17	2·09
7. Wara Seoni		41·94	1·40	40·54	13·16	29·17	1·03	1·28	2·45	2·41
8. Berhampur		51·40	5·74	45·66	10·46	24·65	0·77	0·58	2·74	2·33
9. Kheri-Adhartal		50·23	5·83	44·40	13·41	25·36	1·56	0·43	1·02	0·97
0. Ranchi		45·13	5·23	39·90	9·85	33·12	0·53	1·27	2·22	1·00
1. Chinsura		50·64	7·28	43·36	11·90	26·75	1·76	0·59	2·20	2·09
1. Shahjahanpur	2—3	44·42	5·58	38·84	12·98	31·26	0·50	2·37	6·26	..
2. Samalkot		50·63	2·46	48·17	11·83	25·89	0·85	0·33	2·98	3·56
3. Nagpur		48·95	2·23	46·72	13·94	23·11	1·59	0·36	1·45	2·33
4. Powarkhera		56·39	14·80	41·59	9·29	21·84	1·84	2·20	1·45	0·98
5. Labhandi		50·75	7·80	42·95	11·37	25·97	1·10	1·72	1·68	1·91
6. Chandkhuri		41·64	5·53	36·11	15·37	29·02	0·22	0·43	2·05	4·23
7. Wara Seoni		42·67	1·33	41·34	12·25	29·72	0·97	1·12	2·31	2·38
8. Berhampur		52·62	4·96	47·66	9·78	25·00	0·68	0·59	2·97	2·62
9. Kheri-Adhartal		51·20	7·06	44·14	13·40	23·94	1·81	0·61	1·49	2·06
0. Ranchi		47·72	9·25	38·47	10·09	30·95	0·37	1·15	2·53	1·03
1. Chinsura		50·06	6·18	43·88	11·97	25·64	1·10	2·61	2·06	2·11
1. Shahjahanpur	3—4	43·98	6·80	37·18	13·04	30·25	0·56	2·39	4·22	1·58
2. Samalkot		..	..	..	..	..	..	..	..	..
3. Nagpur		49·72	2·20	47·52	14·68	22·81	1·47	0·43	1·48	3·02
4. Powarkhera		54·80	11·09	42·81	10·12	22·11	2·09	2·60	1·42	1·43
5. Labhandi		50·35	5·67	44·68	13·53	24·39	1·39	1·90	1·54	2·33
6. Chandkhuri		42·81	5·89	36·92	16·46	31·22	0·20	0·37	1·47	4·28
7. Wara Seoni		42·71	1·81	40·90	11·84	30·08	0·92	1·10	2·68	2·45
8. Berhampur		50·72	3·54	47·18	10·06	26·22	0·91	0·65	2·86	1·93
9. Kheri-Adhartal		53·03	6·19	46·84	13·61	23·32	1·68	0·42	0·84	0·72
0. Ranchi		48·18	10·76	37·42	10·18	30·36	0·47	1·41	2·57	0·69
1. Chinsura		50·15	6·18	43·97	11·66	23·74	1·71	0·92	2·15	2·09
1. Shahjahanpur	4—5	45·30	8·63	36·67	12·59	29·31	0·54	2·52	4·42	2·34
2. Samalkot		..	..	..	..	..	..	..	..	..
3. Nagpur		49·64	2·98	46·66	15·43	22·44	2·01	0·38	1·51	2·81
4. Powarkhera		55·49	13·40	42·09	9·77	22·42	2·83	2·84	1·33	1·53
5. Labhandi		51·58	8·31	43·27	12·24	24·52	1·48	2·24	1·50	2·17
6. Chandkhuri		43·31	2·71	40·61	16·99	24·60	0·22	0·32	1·56	5·63
7. Wara Seoni		42·28	2·68	39·60	12·28	29·62	0·93	1·07	2·66	2·39
8. Berhampur		49·79	4·24	45·55	9·74	25·38	0·88	0·63	2·36	2·65
9. Kheri-Adhartal		55·65	11·65	44·00	13·16	22·64	1·55	0·41	0·87	1·28
0. Ranchi		51·25	14·97	36·28	9·25	28·05	0·60	1·28	1·95	0·84
1. Chinsura		50·39	6·93	43·46	11·81	24·89	1·05	0·90	2·14	1·69

IV Soils of per-humid or wet region

Station	Depth (in ft.)	Total silica	Quartz	Combined silica	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
	0—1									
1. Dacca		44·01	3·71	40·30	7·82	29·42	0·19	0·15	1·90	1·61
2. Sirsi		35·21	1·31	33·90	14·93	29·30	0·15	0·94	1·44	1·35
3. Kangra		46·44	7·21	39·23	10·74	25·86	1·38	0·12	2·25	3·89
4. Rangpur		50·06	12·20	39·50	12·49	22·56	0·61	3·50	3·88	2·36
5. Taliparamba		34·53	0·87	33·66	9·65	34·90	0·22	1·01	0·58	0·30
6. Karimganj		44·55	4·25	40·30	9·80	30·09	0·46	2·81	3·25	1·58
7. Sylhet		40·50	4·25	36·25	8·61	30·00	0·24	1·43	2·16	1·24
8. Jorhat		55·27	26·05	29·22	8·11	23·39	0·27	0·79	1·66	1·14
	1—2									
1. Dacca		45·51	2·33	43·18	8·07	32·08	0·12	0·32	1·70	1·66
2. Sirsi		38·42	1·92	36·50	14·91	31·35	0·16	1·12	1·57	1·25
3. Kangra		47·96	9·18	38·78	10·74	25·29	1·29	0·23	2·30	3·67
4. Rangpur		50·50	23·83	26·67	8·90	23·00	0·30	1·29	5·78	3·11
5. Taliparamba		38·68	0·87	37·81	10·14	36·86	0·13	0·78	0·76	0·27
6. Karimganj		45·13	4·35	40·78	10·25	30·10	0·46	2·53	3·10	1·84
7. Sylhet		44·50	4·04	40·46	7·07	34·85	0·18	1·55	2·99	0·24
8. Jorhat		55·27	27·98	27·29	9·82	22·96	0·22	0·81	1·40	1·14
	2—3									
1. Dacca		45·88	2·47	43·41	7·07	32·44	0·10	0·16	2·07	1·36
2. Sirsi		38·45	2·24	36·21	15·51	30·59	0·18	1·11	1·70	1·36
3. Kangra		49·01	9·84	40·07	10·44	25·28	1·12	0·11	2·24	3·77
4. Rangpur		51·70	31·80	18·26	8·80	22·10	0·32	1·74	4·71	0·86
5. Taliparamba		38·95	0·85	38·10	10·70	37·18	0·32	0·66	1·33	0·42
6. Karimganj		43·83	3·81	40·02	9·51	29·46	0·43	2·47	3·02	2·05
7. Sylhet		48·72	4·19	44·53	6·65	33·59	0·10	1·57	2·15	0·78
8. Jorhat		53·09	23·03	30·06	10·61	25·14	0·15	0·63	1·45	0·93
	3—4									
1. Dacca		47·71	2·55	45·16	7·18	32·15	0·08	0·21	2·10	1·45
2. Sirsi		38·05	1·76	36·29	15·12	31·78	0·19	0·98	1·57	1·28
3. Kangra		49·06	11·11	37·95	10·79	26·00	1·12	0·20	2·15	4·03
4. Rangpur		55·95	36·71	19·24	8·63	22·72	0·38	1·64	4·11	1·20
5. Taliparamba		40·79	1·15	39·64	9·41	37·13	0·14	0·27	0·98	0·50
6. Karimganj		43·98	3·72	40·26	10·88	29·56	0·45	2·40	2·38	1·70
7. Sylhet		46·31	2·92	43·39	5·15	34·97	0·10	0·97	2·55	1·36
8. Jorhat		53·92	26·16	27·76	11·93	23·51	0·20	0·60	1·34	1·08
	4—5									
1. Dacca		49·86	3·10	46·76	8·20	32·80	0·11	0·29	2·01	1·50
2. Sirsi		37·73	2·16	35·57	15·51	31·78	0·14	0·95	1·39	1·32
3. Kangra		50·75	14·61	36·14	10·70	27·04	1·05	0·50	2·11	3·86
4. Rangpur		55·57	36·44	19·73	8·72	24·11	0·57	1·71	3·92	1·82
5. Taliparamba		40·71	1·33	39·38	9·49	36·95	0·10	0·36	0·92	0·75
6. Karimganj		45·95	4·34	41·61	9·43	30·55	0·43	1·68	2·38	2·31
7. Sylhet		48·10	3·51	44·59	5·54	34·54	0·07	1·07	2·26	1·41
8. Jorhat		48·37	25·13	23·24	17·77	21·95	0·28	0·64	1·23	1·08

Calcareous soils

Station	Depth (in ft.)	Total silica	Quartz.	Combined silica	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
1. Sakrand	0—1	61·41	34·77	26·64	7·54	17·36	2·81	0·79	1·83	1·59
2. Karachi		41·95	4·99	36·96	9·42	18·83	5·84	3·84	4·96	5·40
3. Peshawar		48·84	10·37	38·47	9·34	25·02	3·27	3·99	4·77	2·81
4. Pusa		37·03	4·44	32·59	10·74	21·67	7·59	5·41	1·92	7·53
5. Padrauna		39·97	13·34	26·63	11·30	14·09	7·77	4·20	4·10	3·47
1. Sakrand	1—2	59·17	29·01	30·16	8·69	19·81	2·17	0·78	2·60	2·40
2. Karachi		43·16	5·99	37·17	9·62	18·56	6·56	3·71	4·59	4·93
3. Peshawar		49·55	7·75	41·80	10·07	26·09	2·69	2·12	4·13	3·04
4. Pusa		40·32	7·48	32·84	10·52	19·17	8·18	2·97	4·28	3·78
5. Padrauna		59·09	28·51	20·58	7·51	9·85	13·86	3·36	3·12	2·80
1. Sakrand	2—3	55·05	21·14	33·91	9·17	21·94	2·95	0·82	2·72	2·49
2. Karachi		41·30	5·07	36·23	9·36	17·99	8·00	0·58	5·10	4·97
3. Peshawar		48·84	7·66	41·18	10·69	23·47	3·40	3·69	4·77	3·26
4. Pusa		46·61	15·81	30·80	10·83	17·82	6·88	3·42	2·94	3·44
5. Padrauna		41·97	27·16	14·81	5·63	7·22	20·91	2·70	2·73	2·29
1. Sakrand	3—4	60·27	24·97	35·30	8·41	19·99	1·45	0·55	2·13	3·11
2. Karachi		41·93	5·79	36·14	10·13	16·69	7·84	3·40	5·42	5·30
3. Peshawar		48·35	7·56	40·79	9·69	24·04	3·87	3·21	3·43	3·70
4. Pusa		40·46	11·65	28·81	9·56	12·20	12·31	3·56	7·45	4·24
5. Padrauna		40·96	30·61	10·35	4·19	4·51	24·76	2·27	2·21	1·49
1. Sakrand	4—5	57·72	20·13	37·59	8·52	11·12	1·50	0·53	2·50	3·56
2. Karachi		43·70	8·71	34·99	8·98	16·89	7·87	3·62	4·90	5·27
3. Peshawar		50·16	11·07	39·09	9·65	26·63	2·83	1·60	4·88	3·62
4. Pusa		42·18	14·48	27·70	9·85	13·32	13·18	1·84	3·65	6·35
5. Padrauna		50·91	36·37	14·54	3·93	6·55	19·77	2·59	2·63	1·88

CLAY ANALYSIS

Average values

Soil type	Depth (in ft.)	Total SiO_2	Quartz.	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
	0—1	49·70	12·01	37·69	9·41	21·80	2·34	2·39	4·03	4·22
	1—2	49·93	10·07	39·86	10·47	22·56	1·93	2·42	3·89	4·32
Arid Soils	2—3	50·65	11·06	39·59	10·29	22·38	1·73	2·16	3·26	3·80
	3—4	50·96	12·04	38·92	10·08	21·76	1·80	2·44	3·33	4·31
	4—5	51·43	14·62	36·81	10·44	20·90	1·81	2·35	3·60	4·41
	0—1	50·96	7·16	43·80	11·31	22·01	2·24	2·12	1·91	3·17
Semi-arid	1—2	51·37	6·85	44·52	11·64	23·10	2·00	2·10	2·02	3·15
	2—3	50·31	6·30	44·01	11·31	23·20	2·02	1·96	1·91	3·20

CLAY ANALYSIS—*contd*

AVERAGE VALUES—*contd*

Station	Depth (in ft.)	Total SiO_2	Quartz.	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
Soils	3—4	50·33	6·03	44·30	11·33	22·70	2·71	1·90	1·84	3·35
	4—5	49·09	7·35	41·74	11·04	21·41	3·81	1·98	1·92	3·59
	0—1	50·17	9·26	40·91	11·99	24·17	1·15	1·12	2·35	1·89
	1—2	48·77	6·39	42·38	11·98	26·83	1·16	1·08	2·30	2·07
Humid	2—3	48·83	6·11	42·72	12·02	26·58	1·00	1·04	2·48	2·32
Soils	3—4	48·64	6·10	42·54	12·52	26·45	1·14	1·22	2·12	2·05
	4—5	49·47	7·65	41·82	12·33	25·39	1·21	1·26	2·03	2·33
Per-humid	0—1	44·03	7·48	36·55	10·27	28·19	0·44	1·34	2·14	1·68
	1—2	45·74	9·31	36·43	9·99	29·56	0·36	1·08	2·45	1·65
Soils	2—3	46·11	9·78	36·33	9·91	29·47	0·34	1·06	2·33	1·44
	3—4	46·97	10·76	36·21	9·89	29·73	0·33	0·91	2·15	1·58
	4—5	47·21	11·33	35·88	10·67	29·97	0·34	0·90	2·03	1·76
	0—1	45·84	13·58	32·26	9·67	19·39	5·46	3·65	3·52	4·16
Calcareous	1—2	48·26	15·75	32·51	9·28	18·70	6·69	2·59	3·74	3·39
	2—3	46·76	15·37	31·39	9·14	17·69	8·43	2·84	3·65	3·29
Soils	3—4	46·40	16·12	30·28	8·40	15·49	10·05	2·60	4·13	3·57
	4—5	48·93	18·15	30·78	8·19	16·90	9·03	2·04	3·71	4·14

COLOUR CLASSIFICATION

Grey and pink soils

Station	Depth (in ft.)	Total SiO_2	Quartz.	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
1. Mianwali	0—1	49·41	11·27	38·14	8·15	20·36	2·42	4·01	3·93	2·94
2. Gurdaspur		43·12	8·95	34·17	11·14	23·68	2·71	0·37	2·59	4·77
3. Lahore		46·97	5·04	41·93	12·82	24·38	1·47	2·29	3·76	5·23
4. Mirpurkhas		50·29	12·45	37·84	9·23	23·51	2·69	0·80	3·45	2·71
5. Makrera		53·06	20·06	33·00	10·44	18·65	1·86	3·78	3·17	2·89
6. Rangpur		50·06	31·80	18·26	12·49	22·56	0·61	3·50	3·88	2·36
7. Berhampur		55·19	10·29	44·90	11·79	19·08	0·94	0·66	3·24	3·29
1. Mianwali	1—2	53·03	13·32	39·71	7·61	21·32	2·38	4·41	3·18	3·28
2. Gurdaspur		45·87	5·24	40·63	12·91	28·10	0·75	0·36	2·59	4·24
3. Lahore		47·82	5·07	42·75	13·24	24·87	1·07	3·10	3·40	4·05
4. Mirpurkhas		49·66	9·47	40·19	10·32	25·87	2·35	0·28	3·55	3·11
5. Makrera		51·80	15·69	36·11	10·97	20·26	1·47	4·15	3·25	2·85
6. Rangpur		50·50	23·83	26·67	8·90	23·00	0·30	1·29	5·78	3·11
7. Berhampur		51·40	5·74	45·66	10·46	24·65	0·77	0·58	2·74	2·33
1. Mianwali	2—3	53·21	13·99	39·22	7·67	20·20	3·00	3·69	3·26	1·72
2. Gurdaspur		46·17	5·93	40·24	11·67	28·64	0·77	0·48	2·58	5·02
3. Lahore		47·91	5·49	42·42	11·27	27·72	0·95	0·71	4·95	3·45

COLOUR CLASSIFICATION—*contd*

Grey and pink soils—contd

Station	Depth (in ft.)	Total silica	Quartz.	Combined silica	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
4. Mirpurkhas	2—3	50·64	9·76	40·88	10·49	25·57	1·33	0·41	1·42	2·47
5. Makrera		50·58	18·59	36·99	10·78	20·45	2·24	4·13	3·05	3·04
6. Rangpur		51·70	12·20	39·50	8·80	22·10	0·32	1·74	4·71	0·86
7. Berhampur		52·62	4·96	47·66	9·78	25·00	0·68	0·59	2·97	2·62
1. Mianwali	3—4	51·00	12·04	38·96	7·46	18·78	3·35	4·77	2·32	2·97
2. Gurdaspur		46·69	6·08	40·61	12·65	28·18	0·72	0·37	2·89	4·70
3. Lahore		49·42	6·98	42·44	12·18	26·16	0·85	0·71	4·16	4·16
4. Mirpurkhas		51·78	12·58	39·20	9·82	25·82	1·41	0·37	3·30	2·36
5. Makrera		38·85	8·26	30·59	9·54	18·77	10·67	4·30	2·09	2·04
6. Rangpur		55·95	36·71	19·24	8·63	22·72	0·38	1·64	4·11	1·20
7. Berhampur		50·72	3·54	47·18	10·06	26·22	0·91	0·65	2·86	1·93
1. Mianwali	4—5	51·42	20·45	31·04	5·44	18·77	3·21	4·42	2·99	4·32
2. Gurdaspur		46·37	7·76	38·61	12·44	26·83	0·75	0·47	2·70	5·25
3. Lahore		48·19	5·95	42·24	10·84	27·60	1·18	1·15	3·83	3·54
4. Mirpurkhas		52·36	13·52	38·84	10·82	25·12	1·68	0·25	3·02	2·79
5. Makrera		39·85	16·54	23·31	8·20	13·70	14·85	4·64	1·70	2·18
6. Rangpur		55·57	36·44	19·13	8·72	24·11	0·57	1·71	3·92	1·82
7. Berhampur		49·79	4·24	45·55	9·74	25·38	0·88	0·63	2·36	2·65

BLACK SOILS

Analytical values—per cent on dry clay

Station	Depth (in ft.)	Total SiO_2	Quartz.	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
1. Samalkot	0—1	50·89	2·71	48·18	11·10	24·06	0·97	0·55	2·60	2·48
2. Nandyal		53·88	2·53	51·35	11·07	26·26	1·64	0·57	1·08	4·09
3. Hagari		53·08	3·36	49·72	10·40	22·02	2·75	0·37	0·83	3·76
4. Koilpatti		55·24	5·45	49·79	7·79	22·08	2·28	4·71	0·92	2·86
5. Padegaon		51·00	1·69	49·31	11·00	19·17	3·22	4·89	0·66	3·22
6. Akola		53·53	8·10	45·43	11·52	20·66	1·94	3·42	1·20	3·95
7. Surat		47·84	3·42	44·42	14·45	24·21	2·87	1·12	0·66	0·17
8. Kharua		51·00	8·03	42·97	8·70	20·09	4·09	3·46	2·18	1·65
9. Indore		55·14	12·28	42·86	10·09	23·02	2·43	3·18	3·59	1·80
10 Nagpur		50·03	5·01	45·02	13·81	24·00	1·29	0·36	1·15	1·53
11. Powarkhera		53·98	11·49	42·49	9·13	23·01	1·97	2·72	1·99	1·38
12. Kheri-adhartal		51·99	7·26	44·73	13·47	23·46	1·72	0·60	1·18	1·38
1. Samalkot	1—2	50·74	2·51	48·23	11·11	24·50	0·94	0·42	3·00	3·89
2. Nandyal		52·38	3·54	48·84	11·63	26·19	1·67	0·65	1·14	4·75
3. Hagari		50·68	8·36	47·32	11·81	25·44	4·73	0·40	1·24	5·32
4. Koilpatti		56·39	8·26	48·13	7·71	21·08	2·09	4·60	0·97	3·20
5. Padegaon		51·02	1·63	49·39	10·95	19·56	3·00	4·80	1·00	4·10

BLACK SOILS—*contd*

Analytical values—per cent on dry clay—contd

Station	Depth (in ft.)	Total SiO_2	Quartz.	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
6. Akola	1—2	53·42	8·22	45·20	12·20	22·08	1·44	2·24	1·08	2·61
7. Surat		50·95	3·41	47·54	16·15	21·86	1·08	1·34	0·65	3·00
8. Kharua		52·34	8·79	43·55	8·89	20·35	4·00	3·34	1·96	1·44
9. Indore		59·95	10·02	49·93	9·94	21·38	2·38	2·69	2·09	1·55
10. Nagpur		51·12	3·63	47·49	13·83	22·97	1·77	0·60	1·47	3·03
11. Powarkhera		56·23	16·10	40·13	8·87	22·77	2·03	2·31	1·67	0·74
12. Kheri-adhartal		56·23	5·83	44·40	13·41	25·36	1·56	0·43	1·02	0·97
1. Samalkot	2—3	50·63	2·46	48·17	11·83	25·89	0·85	0·33	2·98	3·56
2. Nandyal		51·50	2·80	48·70	11·13	25·90	1·35	0·90	1·02	4·29
3. Hagari		50·69	3·35	47·34	8·66	24·52	2·69	0·34	0·97	5·59
4. Koilpatti		55·17	8·73	46·44	6·80	20·38	3·17	4·21	0·94	3·08
5. Padegaon		52·22	1·66	50·56	11·42	18·47	2·91	5·03	0·47	3·66
6. Akola		53·41	7·33	46·08	13·08	21·27	1·63	2·79	1·81	3·28
7. Surat		50·39	2·73	47·66	16·16	22·22	0·94	1·08	0·80	2·36
8. Kharua		50·20	8·02	42·18	9·24	21·07	3·95	3·40	2·03	0·79
9. Indore		50·85	9·09	41·76	10·70	20·64	2·06	3·17	2·07	1·97
10. Nagpur		48·95	2·23	46·72	13·94	23·11	1·59	0·36	1·45	2·33
11. Powarkhera		56·39	14·80	41·59	9·29	21·84	1·84	2·20	1·45	0·98
12. Kheri-adhartal		51·20	7·06	44·14	13·40	23·94	1·81	0·61	1·49	2·06
1. Samalkot	3—4	..	..	..	..	..	..	..	..	..
2. Nandyal		53·23	2·64	50·59	11·08	25·43	1·32	0·49	0·89	5·16
3. Hagari		50·17	3·34	46·83	10·23	22·93	2·64	0·45	1·30	7·86
4. Koilpatti		54·01	6·06	47·95	6·52	20·10	4·28	4·87	0·97	2·63
5. Padegaon		52·21	1·69	50·52	11·42	17·85	2·93	4·37	0·71	2·82
6. Akola		52·91	6·26	46·65	12·46	22·56	1·69	2·02	1·45	2·26
7. Surat		50·47	3·16	47·31	15·82	23·29	0·80	0·93	0·89	1·91
8. Kharua		51·49	8·04	43·45	9·17	22·15	4·11	3·25	2·01	2·38
9. Indore		52·21	8·46	43·75	10·41	23·07	2·26	3·22	3·16	2·06
10. Nagpur		[49·72	[2·20	47·52	14·68	22·81	1·47	0·42	1·48	3·02
11. Powarkhera		[54·80	11·99	42·81	10·12	22·11	2·09	2·60	1·42	1·43
12. Kheri-adhartal		53·03	6·19	46·84	13·61	23·32	1·68	0·42	0·84	0·72
1. Samalkot	4—5	..	..	..	..	..	..	..	..	..
2. Nandyal		53·06	4·77	48·29	10·94	26·96	1·40	0·33	0·83	4·30
3. Hagari		50·19	4·44	45·75	12·41	24·50	2·00	0·40	1·23	6·13
4. Koilpatti		54·23	5·16	49·07	6·10	19·66	4·44	4·91	1·00	3·09
5. Padegaon		37·98	4·04	33·94	7·89	12·95	10·31	2·67	0·72	4·45
6. Akola		51·50	3·72	47·78	13·00	20·83	1·99	2·61	1·52	2·85
7. Surat		50·87	3·31	47·56	14·93	20·79	1·05	1·40	1·16	2·24
8. Kharua		50·33	8·03	42·30	8·50	21·19	5·53	3·48	2·06	1·54
9. Indore		53·85	12·04	41·81	11·11	21·40	2·05	2·73	2·74	2·11
10. Nagpur		49·64	2·98	46·66	15·43	22·44	2·01	0·38	1·51	2·81
11. Powarkhera		53·49	13·40	42·09	9·77	22·42	2·83	2·84	1·33	1·53
12. Kheri-adhartal		55·65	11·65	44·00	13·16	22·64	1·55	0·41	0·87	1·28

Brown and reddish brown soils

Station	Depth (in ft.)	Total SiO_2	Quartz.	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
1. Jorhat	0—1	55·27	26·05	29·22	8·11	23·39	0·27	0·79	1·66	1·14
2. Sylhet		40·50	4·25	36·25	8·61	30·00	0·24	1·43	2·16	1·24
3. Karimganj		44·55	4·25	40·30	9·80	30·09	0·46	2·81	3·25	1·58
4. Waraseoni		42·57	2·26	40·31	12·37	27·44	1·33	1·16	2·75	2·56
5. Anakapalle		44·19	3·32	40·87	16·08	21·79	1·12	2·25	2·16	2·25
6. Coimbatore		55·26	12·00	43·26	10·30	23·67	0·68	0·32	0·97	0·84
7. Tabiji		48·22	9·40	38·82	10·56	18·81	2·81	0·23	2·18	3·45
8. Delhi		52·88	3·81	49·07	13·34	21·68	1·67	0·86	2·77	6·56
9. Shahjahanpur		54·19	22·42	31·77	10·97	19·70	0·92	2·34	4·32	2·06
10. Kangra		46·44	7·21	39·23	10·74	25·86	1·38	0·12	2·25	3·89
11. Lyallpur		50·78	12·11	28·67	10·07	21·23	1·52	1·60	3·65	7·72
12. Haripur (Haz)		48·31	12·21	36·10	10·19	22·08	2·73	3·13	5·10	3·52
1. Jorhat	1—2	55·27	27·98	27·29	9·82	22·96	0·22	0·81	1·40	1·14
2. Sylhet		44·50	4·04	40·46	7·07	34·85	0·18	1·55	2·99	0·24
3. Karimganj		45·13	4·35	40·78	10·25	30·10	0·46	2·53	3·10	1·84
4. Waraseoni		41·94	1·40	40·54	13·16	29·17	1·03	1·28	2·45	2·41
5. Anakapalle		45·37	2·79	42·58	15·92	22·91	1·01	2·16	2·24	2·20
6. Coimbatore		52·87	8·42	44·45	11·18	25·09	0·86	0·33	0·52	0·78
7. Tabiji		50·06	14·45	35·61	7·53	24·23	3·23	0·26	4·98	2·24
8. Delhi		49·60	3·86	45·74	13·64	23·09	1·22	0·88	3·03	4·86
9. Shahjahanpur		46·12	7·60	38·52	12·87	29·27	0·68	2·29	4·10	1·51
10. Kangra		47·96	9·18	38·78	10·74	25·29	1·29	0·23	2·30	3·67
11. Lyallpur		49·98	11·57	38·41	12·66	19·39	1·46	1·46	3·39	7·25
12. Haripur (Haz)		47·03	5·91	41·12	11·30	23·67	1·53	3·54	5·45	3·65
1. Jorhat	2—3	53·09	23·03	30·06	10·61	25·14	0·15	0·63	1·45	0·93
2. Sylhet		48·72	4·19	44·53	6·65	33·59	0·10	1·57	2·15	0·78
3. Karimganj		43·83	3·81	40·02	9·51	29·46	0·43	2·47	3·02	2·05
4. Waraseoni		42·67	1·33	41·34	12·25	29·72	0·97	1·12	2·31	2·38
5. Anakapalle		44·61	2·90	41·71	15·76	22·94	1·23	2·12	2·31	2·28
6. Coimbatore		53·33	10·12	43·21	10·02	25·60	1·51	0·30	0·60	1·34
7. Tabiji		47·82	8·87	38·95	9·60	24·51	3·02	0·37	2·01	3·08
8. Delhi		49·76	3·82	45·94	13·37	23·63	1·87	0·39	2·97	4·76
9. Shahjahanpur		44·42	5·58	38·84	12·98	31·26	0·50	2·37	6·26	..
10. Kangra		49·91	9·84	40·07	10·44	25·28	1·12	0·11	2·24	3·77
11. Lyallpur		50·88	13·10	37·78	11·80	20·16	1·27	1·12	3·44	7·14
12. Haripur (Haz)		47·88	7·40	40·48	11·18	23·58	1·33	3·43	1·90	3·89
1. Jorhat	3—4	53·92b	26·16	27·76	11·93	23·51	0·20	0·60	1·34	1·08
2. Sylhet		46·31	2·92	43·39	5·15	34·97	0·10	0·97	2·55	1·36
3. Karimganj		43·98	3·72	40·26	10·88	29·56	0·45	2·40	2·38	1·70
4. Waraseoni		42·71	1·81	40·90	11·84	30·08	0·92	1·10	2·68	2·45
5. Anakapalle		47·04	2·40	44·64	14·63	23·44	1·27	2·10	1·64	2·57

BROWN AND REDDISH BROWN SOILS—*contd*

Station	Depth (in ft.)	Total SiO_2	Quartz.	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
6. Coimbatore	3—4	53·43	11·38	42·05	9·55	21·43	3·00	0·26	0·65	1·47
7. Tabiji		50·66	10·25	40·41	10·12	23·40	2·44	0·49	2·44	4·06
8. Delhi		52·14	5·48	46·66	14·18	21·79	1·85	0·59	2·92	4·24
9. Shahjahanpur		43·98	6·80	37·18	13·04	30·25	0·56	2·39	4·22	1·68
10. Kangra		49·06	11·11	37·95	10·79	26·00	1·12	0·20	2·15	4·03
11. Lyallpur		53·68	17·53	36·15	11·87	19·16	1·18	1·24	3·12	7·02
12. Haripur (Haz)		47·88	5·99	41·39	11·16	23·26	1·26	3·38	4·59	4·88
	4—5									
1. Jorhat		48·37	25·13	23·24	17·77	21·95	0·28	0·64	1·28	1·08
2. Sylhet		48·10	8·51	44·59	5·54	34·54	0·07	1·07	2·26	1·41
3. Karimganj		45·95	4·34	41·61	9·43	30·55	0·43	1·68	2·38	2·31
4. Waraseoni		42·28	2·68	39·60	12·28	29·62	0·93	1·07	2·66	2·39
5. Anakapalle		47·05	2·34	44·71	14·98	22·78	1·45	2·21	1·78	2·64
6. Coimbatore		..	..	..	..	..	..	..	..	..
7. Tabiji		52·07	18·99	33·08	9·68	19·25	3·42	0·29	3·01	5·73
8. Delhi		51·71	5·86	45·85	13·49	21·36	2·98	0·48	2·69	4·22
9. Shahjahanpur		45·30	8·63	36·67	12·59	29·31	0·54	2·52	4·42	2·34
10. Kangra		50·75	14·61	36·14	10·70	27·04	1·05	0·50	2·11	3·86
11. Lyallpur		54·63	18·60	36·03	13·72	15·85	1·21	1·42	2·91	6·89
12. Haripur (Haz)		47·26	5·92	41·34	11·79	23·87	1·14	3·32	5·49	3·65

IV. RED OR LIXIVIUM SOILS

Station	Depth (in ft.)	Total SiO_2	Quartz.	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
	0—1									
1. Ranchi		47·04	9·51	37·53	11·63	28·67	1·37	1·34	2·21	0·98
2. Chandkhuri		45·54	14·47	31·07	14·67	25·47	0·11	0·49	1·72	1·88
3. Taliparamba		34·53	0·87	33·66	9·65	34·90	0·22	1·01	0·58	0·30
4. Sirsi		35·21	1·31	33·90	14·93	29·30	0·15	0·94	1·44	1·35
	1—2									
1. Ranchi		45·13	5·23	39·90	9·85	33·12	0·53	1·27	2·22	1·00
2. Chandkhuri		40·98	5·02	35·96	15·69	29·64	0·23	0·59	2·17	2·99
3. Taliparamba		38·68	0·87	37·81	10·14	36·86	0·13	0·78	0·76	0·27
4. Sirsi		38·42	1·92	36·50	14·91	31·35	0·16	1·12	1·57	1·25
	2—3									
1. Ranchi		47·72	9·25	38·47	10·09	30·95	0·37	1·15	2·53	1·03
2. Chandkhuri		41·64	5·53	36·11	15·37	29·02	0·22	0·43	2·05	4·23
3. Taliparamba		38·95	·85	38·10	10·70	37·18	0·32	0·66	1·33	0·42
4. Sirsi		38·45	2·24	36·21	15·51	30·59	0·18	1·11	1·70	1·36

IV. RED OR LIXIVIUM SOILS—*contd*

Station	Depth (in ft.)	Total SiO_2	Quartz.	Combined SiO_2	F_2O_7	Al_2O_3	CaO	MgO	K_2O	Na_2O
	3—4									
1. Ranchi		48·18	10·76	37·42	10·18	30·36	0·47	1·41	2·57	0·69
2. Chandkhuri		42·81	5·89	36·92	16·46	31·22	0·20	0·37	1·47	4·28
3. Taliparamba		40·79	1·15	39·64	9·41	37·13	0·14	0·27	0·98	0·50
4. Sirsi		38·05	1·76	36·29	15·12	31·78	0·19	0·98	1·67	1·28
	4—5									
1. Ranchi		51·25	14·97	36·28	9·25	28·05	0·60	1·28	1·95	0·84
2. Chandkhuri		43·32	2·71	40·61	16·99	24·60	0·22	0·32	1·56	5·63
3. Taliparamba		40·71	1·33	39·38	9·49	36·95	0·10	0·36	0·92	0·75
4. Sirsi		37·73	2·16	35·57	15·51	31·78	0·14	0·95	1·39	1·32

CLAY ANALYSIS

AVERAGE VALUE

Soil type	Depth (in ft.)	Total SiO_2	Quartz.	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
Grey and pink	0—1	49·77	11·27	38·50	10·87	21·75	1·81	2·20	3·43	3·46
	1—2	50·01	11·19	38·82	10·63	24·01	1·30	2·02	3·51	3·28
	2—3	50·17	12·22	37·95	10·06	24·24	1·33	1·63	3·28	2·74
	3—4	49·20	12·31	36·89	10·05	23·81	2·61	1·83	3·03	2·77
	4—5	49·18	14·99	34·19	9·46	23·07	3·30	1·90	2·93	3·22
Black soils	0—1	52·30	5·94	46·36	11·04	22·67	2·26	2·16	1·50	2·36
	1—2	52·96	6·28	46·68	11·38	22·79	2·22	1·99	1·44	2·88
	2—3	51·81	5·86	45·95	11·30	22·44	2·06	2·04	1·46	2·83
	3—4	52·21	5·46	46·75	11·41	22·33	2·30	2·09	1·37	2·93
	4—5	51·17	6·69	44·48	11·20	21·43	3·20	2·01	1·36	2·94
Brown and reddish brown soils	0—1	48·60	9·94	38·66	10·93	23·81	1·26	1·42	2·77	3·07
	1—2	47·98	8·46	39·52	11·25	25·84	1·10	1·44	3·00	2·65
	2—3	48·07	7·83	40·24	11·18	26·24	1·13	1·33	2·81	2·95
	3—4	48·70	8·80	39·90	11·26	25·57	1·20	1·31	2·56	3·04
	4—5	48·50	10·06	38·44	12·00	25·10	1·23	1·38	2·81	3·32
Red soils	0—1	40·58	6·54	34·04	12·72	29·59	0·46	0·95	1·49	1·13
	1—2	40·80	3·26	37·54	12·65	32·74	0·26	0·94	1·68	1·38
	2—3	41·69	4·47	37·22	12·92	31·94	0·27	0·84	1·90	1·76
	3—4	42·46	4·89	37·57	12·79	32·63	0·25	0·76	1·65	1·69
	4—5	43·25	5·29	37·96	12·81	30·35	0·27	0·73	1·46	2·14

A RELATIVE STUDY OF SOIL AND ARTIFICIAL MULCHES IN CONSERVING SOIL MOISTURE

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The effect of artificial mulches such as those of straw and paper has been studied in the western countries, more especially in the United States of America, in great detail. Harris and Jones [1918], working under dry farming conditions, came to the conclusion that straw mulches were more effective in preventing evaporation than soil mulches. Similar results were obtained by Martin [1935] in Africa, and Shaw [1929] in U.S.A. Smith [1931] studied the effect of paper mulches, and found them very efficient in conserving moisture. A conference on mulching was held in Leningrad, U.S.S.R., in 1932 and as a result of the discussions held there, it was agreed that paper mulches conserved more moisture, and were more effective than soil mulch. Maher [1936], while reviewing the work on mulches, also came to the same conclusion, i.e. artificial mulches conserve more moisture than soil mulch.

Recently, the researches of Blomqoist [1940] in Finland, Paul [1941] in Ceylon, Turner [1940] in Trinidad and Beach [1941] in U.S.A., again support the findings of other workers regarding the efficiency of artificial mulches. Russell [1940], however, maintains that artificial mulches are only effective during periods of frequent rains, but are of little value when rains are scanty.

No work of this nature has been reported from any quarters in this country. Therefore, experiments were conducted to study the relative effect of soil and artificial mulches under dry-farming conditions at Rohtak. The importance of this work is greatly enhanced, from the point of view of dry-farming studies, as the main problem in this case is to reduce evaporation to a minimum and conserve maximum amount of moisture received in the form of rainfall for the use of the crop. A detailed investigation on the relative effect of soil mulch and weeding out has already been submitted by the authors for publication, and the work reported here is in continuation of that work.

The experiments were carried out in (i) pots, (ii) observation plots, and (iii) randomized field experiments.

Experimental

I. Pot experiment

Twenty-four pots, each 18 in. long and 1 ft. in diameter were placed under the following treatments :

1. Artificial mulch 2 in. thick.
2. Artificial mulch 4 in. thick.
3. Soil mulch 2 in. thick.
4. Soil mulch 4 in. thick.
5. Soil mulch 6 in. thick.
6. Control (without mulch).

Each pot was filled with 80 lb. of medium loam soil, leaving 4 in. of empty space at the top. Mechanical composition of the soil is given below :

Clay (0·002 mm.)	Silt (0.02 mm.)	F. Sand (0·20)	$CaCo_3$
16·31	35·80	50·38	0·22

There were four replications of each treatment, and the data was examined statistically. To each pot were added 18 lb. of water on 20 July 1937, and immediately after the addition, eight pots were covered with artificial mulch of *bajra* stalk (*Pennisetum-typhoideum*). The remaining pots came into 'wattar' condition on 26 July 1937, and excepting four pots which were to serve as controls, the others were cultivated to different depths to form soil mulch 2 in., 4 in. and 6 in. deep. The pots were kept in the open, but were embeded in the soil in order to ensure uniform conditions of temperature. They were weighed from time to time, and losses of moisture from them were determined. The results are given in Table I.

TABLE I

Loss of moisture from pots under straw and soil mulch in lb.

	First period 20 July 1937 to 9 May 1938											
	20/7 to 26/7 1937	9/8 1937	19/8 1937	31/8 1937	20/9 1937	13/10 1937	21/12 1937	12/1 1938	12/2 1938	12/3 1938	12/4 1938	9/5 1938
Artificial mulch 2 in.	1·89	2·06	4·12	1·87	+4·06	2·50	5·00	+3·19	1·87	1·56	1·56	0·80
Artificial mulch 4 in.	1·81	1·44	4·44	1·64	+3·00	3·62	5·56	+3·00	1·56	2·00	2·00	0·40
Soil mulch 2 in.	6·94	1·50	1·75	0·54	+1·62	1·06	4·00	+1·12	1·50	2·12	1·44	1·30
„ „ 4 in.	7·12	2·19	2·31	0·17	+3·50	0·94	4·00	+2·31	1·19	1·56	1·81	2·41
„ „ 6 in.	7·31	1·75	2·25	0·17	+3·75	1·00	3·75	+2·31	1·12	1·44	1·81	2·20
Control	7·12	4·25	3·94	0·86	+4·00	1·44	1·62	+2·81	1·38	1·31	1·12	0·72
Observed P	<0·01	<0·01	<0·01	<0·01	..	..	..	..	..	..	..	..
Critical difference	2·64	0·62	1·05	0·77	..	..	..	..	..	..	..	..
S. E. per cent mean	16·8	9·8	11·2	3·0	..	..	..	..	..	..	..	..

	Second period 10 May to 1 June 1938											
	10/5 to 13/5 1938	15/5 1938	17/5 1938	19/5 1938	21/5 1938	24/5 1938	27/5 1938	1/6 1938				
Straw mulch 2 in.	5·69	1·75	1·19	1·62	1·94	1·44	0·75	0·19	..	..	..	..
„ „ 4 in.	4·75	1·60	1·31	1·13	1·88	1·50	1·13	0·62	..	..	..	
Soil „ 2 in.	7·38	0·62	0·69	0·62	0·75	0·81	0·69	0·50	..	..	..	.
„ „ 4 in.	8·81	0·81	0·19	0·56	0·69	0·81	0·62	0·13	..	..	..	..
„ „ 6 in.	8·69	1·06	0·25	0·50	0·69	0·56	0·50	0·25	..	..	..	..
Control	9·06	2·13	1·13	0·56	0·88	0·44	0·62	0·13	..	..	..	..
Observed P	<0·01	<0·01	<0·01	<0·01	..	..	..	..	..	..	..	..
Critical difference	0·35	0·48	0·42	0·23	..	..	..	..	..	..	..	..
S. E. per cent mean	9·20	21·80	17·6	6·6	..	..	..	..	..	..	..	..

First period 20 July 1937 to 9 May 1938

There was intense evaporation from all the pots other than those under artificial mulch from 20 to 26 July 1937. The loss of moisture during this interval was significantly less from pots under artificial mulch than from pots under other treatments (from which the loss was nearly the same). The loss of moisture from the pots under artificial mulch and those under soil mulch and the control was 1·25, 7·12 and 7·12 lb. respectively. When pots were weighed after 14 days on 9 August 1937, the loss of moisture due to evaporation from the pots under all the treatments was the same except from the controls, which recorded greater losses. On 19 August 1937 (a month after the start of the experiment), the losses from the pots under artificial mulch became more than those under soil mulch, and were almost equal to those from controls. On 31 August 1937 (a month and a half after the start of the experiment), the losses of moisture from the artificial mulch became significantly higher than those under all the other treatments. From this date onward till 9 May 1938, the losses from artificial mulch remained the highest, followed by those under soil mulch, and were lowest in the case of control pots except after a shower of rain on 18 September 1937, when the evaporation from the controls was slightly more than those under soil mulch, but the differences were not significant statistically.

Second period 10 May to 1 June 1938

It was decided to study the effect of artificial mulches on the conservation of moisture during the driest and the hottest month of the year, but

it was observed that bulk of the water had already evaporated from the pots, and moisture content had fallen much below the wilting coefficient (5·37 per cent). Therefore, 19 lb. of water were added to each pot on 10 May 1938. Soil became fit for cultivation on 13 May 1938, and soil mulch was formed in pots under this treatment. Losses of moisture from 10 to 13 May 1938 were least from the pots under artificial mulch. These results again support the observation already made, viz. the loss of moisture under artificial mulch is least in the beginning. However, one noteworthy difference is, that the absolute loss from all the pots was higher during this period of three days than it was in six days interval from 20 to 26 July 1937. On 15 May 1938, two days after the formation of soil mulch, the evaporation from the pots under artificial mulch became more as compared to soil mulched pots, but was less than those of controls. However, on 17 May 1938, the loss from pots under straw mulch, became even more than the control pots. Loss of moisture remained highest from straw mulch till 27 May 1938, when it became more or less the same from other treatments.

When straw mulch 2 in. thick is compared with 4 in. thick it is observed, that there are more losses from 2 in. thick mulch in the beginning, but after 10 to 15 days these become more from 4 in. straw mulch. In the hot season total loss of moisture was more from 2 in. straw mulch. A 2 in. mulch is quite adequate in winter, bu during the summer 4 in. mulch is decidedly bette Harris and Bracken [1917] recommend 2 in. thic layer of straw, but the results at this station sho that thickness of mulch depends on the seaso

Absorption of rain water

All the pots were weighed on 20 Septemb 1937 and 12 January 1937, after 2·69 and 1·10 i of rains respectively. The results show th there was more absorption of rain water und straw mulch. The data obtained on 20 Septemb 1937 is not significant but those obtained on January 1937 gave statistically significant figure

Total loss of water from the pots during the fir period from 20 July 1937 to 9 May 1938

Total loss from each pot on different dat and the percentage loss of the water added f both the periods are given in Table II.

When the pots under straw mulch are compar with those under soil mulch it will be seen th the total amount of water lost remained l from pots under straw mulch from 20 July 31 August 1937. On this date, 53·4 and 6 per cent of the total water added had evapora from straw, and soil mulch respectively. L on the total amount of water lost from str mulch became more, and on 12 April 1938, 22·6 of water were lost as against 20·9 lb. from mulch, which means an extra loss of 2 lb. of wa under straw mulch. The straw mulch pots did show any marked variation amongst themsel

TABLE II

	Total loss of moisture from 20 July 1937								
	20/7 1937	9/8 1937	19/8 1937	31/8 1937	13/10 1937	2/12 1937	12/2 1938	12/3 1938	12/ 19
Artificial mulch 2 in.	1·88	3·94	8·06	9·94	12·44	17·44	19·31	20·94	22·
„ „ 4 in.	1·81	3·25	7·69	9·31	12·94	18·50	20·06	20·14	22·
Soil „ 2 in.	6·94	8·44	10·19	11·69	11·75	15·75	17·25	19·47	20·
„ „ 4 in.	7·12	9·31	11·62	11·75	12·69	16·69	17·88	19·14	21·
„ „ 6 in.	7·31	9·06	11·31	11·44	12·44	16·19	17·31	18·59	20·
Control	7·12	11·38	15·31	15·94	17·38	17·35	20·38	20·18	21·
Observed P	<0·01	<0·01	<0·01	..	<0·05	>0·05	>0·05	>0·05	>0·
Critical difference	2·64	2·94	2·56	..	2·73	..	..	..	..
S. E. of mean	16·8	13·2	8·80	..	6·9	8·2	4·2	4·5	
	Percentage loss of moisture of the total water added on 20 July 1937								
Artificial mulch	10·3	20·0	43·8	53·5	70·5	99·8	109·4	114·1	12
Soil mulch	39·5	49·6	61·3	62·7	68·3	90·0	97·1	105·9	11
Control	39·6	63·2	85·0	88·5	96·6	105·6	113·2	112·1	12

TABLE II—*contd.*

	Total loss of moisture from 10 May 1938							
	10/5 to 13/5 1938	15/5 1938	17/5 1938	19/5 1938	21/5 1938	24/5 1938	27/5 1938	1/6 1938
raw mulch 2 in.	5·69	7·44	8·63	10·25	12·19	13·63	14·50	14·75
„ „ 4 in.	4·75	6·25	7·50	8·50	10·31	12·00	13·13	13·56
il „ 2 in.	7·38	8·00	8·69	9·38	10·12	10·94	11·63	12·12
„ „ 4 in.	8·81	9·63	9·75	10·31	11·00	11·81	12·44	12·56
„ „ 6 in.	8·69	9·69	9·94	10·44	11·12	11·69	12·19	12·44
ntrol	9·06	11·19	12·31	12·88	13·75	14·19	14·81	15·00
bserved P	<0·01	<0·01	<0·01	<0·01	<0·01	<0·01	<0·01	<0·01
itical difference	0·80	0·44	0·31	0·63	0·98	1·05	1·05	1·05
E. of mean	3·8	5·4	3·4	2·2	2·8	2·7	2·6	2·5
	Percentage loss of moisture of the total water added on 10 May 1938							
raw mulch	29·0	38·0	44·8	52·1	62·5	71·2	76·8	78·7
il mulch	46·0	50·6	52·5	55·8	59·8	63·8	67·2	68·7
ntrol	50·3	62·2	69·3	71·5	76·4	79·7	82·3	83·3

From pots under soil mulch 39·5 per cent of e total water added had disappeared within x days, the time required for attaining 'wattar' ndition and the preparation of soil mulch. After ne formation of soil mulch the rate of evaporation eatly slowed down from these pots. From 5 July to 9 August 1937 loss from soil and arti-ial mulched pots amounted to 10·4 and 9·7 r cent and that from 9 to 19 August 1937 amount-l to 11·7 and 23·8 per cent respectively, of the tal water added.

In the controls moisture losses were more, and 31 August 1937 water lost was 88·8 per cent, hile in the case of pots under artificial mulch d soil mulch it was 53·4 and 62·8 per cent res-ctively. This difference narrowed down with me and on 2 December 1937, the total water st from all the pots became the same.

otal loss of water from pots during second period from 10 May to 1 June 1938

The straw mulched pots lost 27·2 per cent of the tal moisture from 10 to 13 May 1938, a period hich took other pots to come into 'wattar' con-tion. During the same period, the soil mulched d control pots lost 45·1 and 46·3 per cent of the tal water added. The total percentage loss mained less in straw mulch till 21 May 1938, nen it became equal to the water lost from pots der soil mulch. On this date the percentage oisture lost from straw and soil mulch was 58·4 and 58·3 per cent respectively. Later on, the total water lost became more from straw mulch. On 1 June 1938, 73·2 and 67·1 per cent of water added was lost from the pots under straw and soil mulch respectively. After the formation of soil mulch the evaporation from these pots decreased considerably. From 13 to 15 May 1938 there was a loss of 4·4 per cent from the pots under soil mulch, while from the pots under straw mulch loss was 8·1 per cent. Later on, losses from soil mulch on different dates amounted to 2 to 3 per cent, while from straw mulch they varied from 5 to 9 per cent. On the other hand, in controls there was a gradual loss.

The water lost between different dates went on decreasing with time, and it ranged between 10·9 and 1·0 per cent during 15 May to 1 June 1938. Total water lost during this period from pots under straw, soil mulch, and controls was 73·2 , 67·1, and 76·7 per cent respectively, the loss being maximum from controls, and minimum from soil mulch.

Meteorological factors and evaporation

When the rate of evaporation during the two periods is compared, it will be observed that greater evaporation takes place in the second period than in the first. During the first six days of the first period from 20 to 26 July 1937, there was loss of 10·4, 39·5, and 39·5 per cent as against 27·2, 45·1, and 46·3 per cent in first three days of

the second period (10 to 13 May 1938) from pots under straw mulch, soil mulch, and controls respectively. After a period of 19 days, percentage loss of water in the first period was 19·8, 49·6, 63·2, and in the second period it was 74·7, 65·4, and 75·3 per cent, from the straw mulched, soil mulched and control pots respectively. From the meteorological data given in Table III it will be seen that dry conditions prevailed in the second period and it is due to this intense drought that greater losses occurred.

TABLE III

Dates	Temperature		Relative humidity	Saturation deficit	Wind velocity
	Max.	Min.			
20 July to 19 August 1937	95·8°F.	79·5°F.	73	14·12	6·5
10 May to 6 June 1938	108·0°F.	80·8°F.	34	30·04	10·2

The dry weather increased evaporation much more in pots covered with artificial mulch than in others. The increase in loss through evaporation in the second period (due to more dry conditions) when compared with the first was more from pots under straw mulch than soil mulch or control pots (51·9 per cent in straw mulch as against 15·8 and 12·1 per cent from the soil mulch and control pots respectively).

Distribution of moisture in different layers

In order to ascertain the distribution of moisture in pots under different treatments, soil samples were obtained, in three sections, 0-3 in., 3-6 in. and 6-12 in. The first sampling was done on 13 October 1937 when the sowing of winter crop starts, and the second on 9 May 1938, when maximum amount of moisture had evaporated. The results are given in Table IV.

TABLE IV

Moisture as percentage on oven dry soil

	Artificial mulch		Soil mulch			Control	Observed P	C. D.	S. E. mean
	2 in.	4 in.	2 in.	4 in.	6 in.				
				13 October 1937					
0-3 in. . .	14·00	13·64	7·59	7·84	7·17	2·97	<0·01	3·76	12·6
3-6 in. . .	13·25	15·73	9·83	10·18	9·66	9·09	<0·01	2·68	8·1
6-12 in. . .	14·54	14·79	10·13	12·96	13·03	9·98	<0·01	2·48	6·5
				9 May 1938					
0-3 in. . .	0·91	0·94	0·62	1·09	1·56	0·64	<0·05	0·59	20·8
3-6 in. . .	1·97	1·55	1·41	1·95	2·57	1·34	<0·05	0·84	15·5
6-12 in. . .	3·94	3·76	3·05	3·47	3·85	3·23	<0·05	0·61	6·2

On 13 October 1937, moisture in all the layers of pots under straw mulch was much higher than those under soil mulch, or controls. In 0-3 in. layer of pots under straw mulch moisture was 14·00 to 13·64 per cent, while under the soil mulch and the controls it was 7·60 and 2·97 per cent respectively. In one foot layer, there was about 4 and 6·5 per cent more moisture present in pots under straw mulch, than those under soil mulch or controls respectively. Moisture under cover of 2 in. and 4 in. thick straw mulch was the same.

Under soil mulch there was about 2 per cent more moisture than in controls. In pots under soil mulch of different depths, there was no difference except in 6-12 in. layer of the pots under 2 in. soil mulch, in which case there was about 3 per cent less moisture than that under 4 in. or 6 in. soil mulch.

On 9 May 1938 moisture fell much below the wilting coefficient in all the depths. At this stage there was no significant difference between the moisture content of pots under artificial or soil mulch, though the pots under mulches contained more moisture when compared to controls, but significant differences were observed only betwen 6 in. soil mulch and control. These results suggest that in summer season a deep layer of soil mulch is more effective.

II. Observation plots

In September 1937 plots measuring 33 ft. × 16½ ft. were laid out in fields 92 and 78, representing two extreme types of profiles met at the station. Mechanical analysis of these types is given in Table V.

TABLE V

Mechanical analysis

(Percentage on oven dry soil)

	Field No. 78				Field No. 92			
	Clay 0·002 mm.	Silt 0·02 mm.	F. Sand 0·2 mm.	C. Sand 0·4 mm.	Clay 0·002 mm.	Silt 0·02 mm.	F. Sand 0·2 mm.	C. Sand 0·4 mm.
0-6 in.	9·25	24·30	65·38	1·07	16·31	35·80	50·38	—
6-12 in.	13·50	19·32	67·50	1·59	21·65	40·04	38·25	0·05
2 ft.	21·02	22·36	54·95	1·08	34·08	32·58	31·52	0·53

In each of these fields two plots were laid out, one was covered with a 3 in. thick layer of plant trash, and the other occasionally cultivated 3 in. deep to form soil mulch. The covering was done immediately after a shower of 2·19 in. on 16 September 1937, and the soil mulch was produced with the help of a spade as soon as the plots attained 'wattar' condition. Moisture was estimated on different dates down to 2 ft. depth, and results are given in Table VI.

The data from the plots support the results already obtained from the pot experiments. There has always been more moisture in artificial mulch plots than soil mulch throughout the period from 18 September 1937 to 17 June 1938. Differences were more marked after the winter rains on 1 January 1938 than during the period from 18 September 1937 to 1 January 1938. From 1 January to 17 June 1938, the differences were more in the heavy type than in the light type except on 26 January 1938, when there was 0·73 per cent more moisture in the light type than heavy type in 2 ft. column of the soil. From 5 to 25 April 1938 there were no differences in the case of light type, but from 25 April 1938 onwards again differences developed, and moisture in artificial mulched plots became more than soil mulched plots, and this difference persisted till 7 June 1938. In the heavy type, moisture in the artificial mulched plots remained always more than soil mulched plots, the difference on 7 June 1938 in 0-6 in., 6-12 in. and 2nd ft. being 2·09, 3·09 and 1·67 per cent respectively. On the same day in the corresponding layers of light type the differences were much less (being 0·09, 0·42 and 0·37 per cent respectively).

TABLE VI

Observations plots.

(Percentage on oven dry soil)

Dates (1937-38)		18·9	30·10	2·12	3·1	28·1	25·2	26·3	5·4	15·4	25·4	5·5	15·5	27.5	7·6		
Field No. 92																	
rtificial mulch	0-6 in.	22·10	10·51	7·53	6·69	12·44	13·08	12·42	12·15	11·52	10·46	9·46	8·33	6·31	6·87	5·02
oil mulch	0-6 in.	18·66	8·97	7·07	6·48	17·24	10·98	6·97	4·05	4·05	4·59	5·57	3·22	3·57	2·87	3·11
rtificial mulch	6-12 in.	21·68	14·66	12·15	9·48	15·56	12·12	12·84	11·87	12·05	11·90	13·54	10·19	7·90	8·21	8·28
oil mulch	6-12 in.	10·02	13·13	12·22	10·37	14·44	11·61	9·83	10·34	7·23	9·15	9·24	5·07	8·37	5·94	5·19
rtificial mulch	2nd ft.	20·20	17·38	15·51	6·34	14·48	14·96	15·82	12·28	15·34	15·97	15·48	13·16	12·80	13·23	12·07
oil mulch	2nd ft.	14·20	14·61	14·77	12·33	12·65	12·34	11·67	14·75	11·36	11·71	11·30	9·81	10·65	9·96	10·40
Field No. 78																	
rtificial mulch	0-6 in.	15·35	8·86	6·40	6·27	14·44	13·28	10·95	5·91	5·00	4·66	6·57	5·66	3·61	3·14	2·65
oil mulch	0-6 in.	16·00	7·20	5·32	4·27	15·50	8·92	3·75	4·04	4·54	4·50	3·95	2·70	2·47	2·56	2·56
rtificial mulch	6-12 in.	15·57	11·04	9·03	8·67	12·08	12·35	12·25	7·90	7·93	6·63	8·98	8·56	5·94	5·26	4·91
oil mulch	6-12 in.	16·42	10·33	8·47	7·71	13·25	10·01	8·07	5·60	7·15	5·29	6·05	3·59	5·84	4·20	4·43
rtificial mulch	2nd ft.	15·50	12·98	11·20	10·35	11·08	11·87	11·82	10·09	10·66	10·15	9·07	12·93	9·10	8·47	8·26
oil mulch	2nd ft.	16·52	12·10	10·48	10·03	11·06	10·32	9·82	9·79	10·00	7·97	9·08	7·54	8·86	8·12	7·89

III. Randomized field experiments

Two types of soil, light loam and medium loam, were selected for this work. In each type of soil eight plots were laid out, and the treatments were arranged in paired groups, four plots being under each treatment. The size of each plot was 33 ft. × 10 ft. The experiment was started in the beginning of March 1939. Instead of *bajra* stalks, which were used in the observation plots, cotton stalks were used as artificial mulch.

Soil moisture 1939-40

Moisture determinations were started from 27 March 1939, and were carried out till 1 April 1940, when cotton was sown in these plots. During this interval 20 samplings down to 3 ft. depth were made and moisture determined. The results are given in Tables VII (*a*) and VII (*b*).

Before 27 March there were 1·42 in. of rain which were received in four showers. Due to these rains there was increase in all the layers down to 3 ft. in plots under artificial mulch in the light type, but in the case of heavy type there were no differences. There were differences in the moisture content of all the layers of the light type till 12 April, but on 30 April they disappeared in 0-6 in. layer, though differences in the lower layers were significant. Summer rains started from 6 June 1939, and the moisture estimated on 30 June after 2·79 in. of rains showed that though there was more moisture in the artificial mulched plots in the light type yet there were no such differences in the case of heavy type. Due to subsequent rains the differences between the artificial and soil mulched plots of the heavy type also became significant on 19 July 1939. The differences were more in the heavy type than in the light type.

From 19 July to 2 August there were no rains, and the results of moisture estimated on 22 August show that there was no difference in the artificial mulched and soil mulched plots of the light type, though there were significant differences in the case of the heavy type. From this date onward there were no significant differences, but after a shower of 1·09 in. on 18 September differences again became significant in both the soils, and they persisted till 19 October. On this day there was more moisture in the artificial mulched plots down to 2 ft. depth. There were no significant differences from 19 October 1939 to 13 February 1940. During this period though the differences were not significant there was more moisture in the artificial mulched plots and the differences were more in the heavy type than in the light type in which differences were small and insignificant. Moisture estimated on 13 February after 3·03 in. of rains showed that the differences between the treatments had become again significant, and there were significant differences in each layer down to 3 ft. depth. These differences persisted till 30 March 1940 when cotton was sown in the light type. Maximum differences occurred in the surface 6 in., and they decreased with the depth. Saving of moisture due to artificial mulch in 3 ft. column of light and heavy types was 2·11 and 1·26 per cent respectively.

Moisture estimated after the rains showed that there was always more moisture (2 to 3 per cent) and it travelled to deeper depths in the artificial mulched plots than in the soil mulched plots. During rainless periods there were losses of moistures from the plots under both the treatments but the losses were more from artificial mulch than from soil mulch.

Soil moisture 1940-41

After the harvesting of cotton, moisture was estimated on 25 December 1940 (Table VIII), and on this date there was no difference between the moisture content of the mulched and the unmulched plots. Mulch was spread on 19 January 1941 after 2·42 in. of rains. Moisture estimated on 14 February 1941 showed that there was more moisture in the plots under artificial mulch. From 14 February to 18 September 1941 moisture was determined after a shower of rain, and the results obtained show that there was more moisture in all the layers of the artificial mulched plots. From 18 September to 8 November 1941, there were no rains, and the moisture estimated on 8 November 1941 showed that there were no significant differences between the moisture content of plots under both the treatments. In the upper first foot layer there was slightly more moisture in the plots under soil mulch but in the third foot layer of the artificial mulches there was 1 per cent more moisture. There was always more absorption of rain water by the plots under artificial mulch and these results support the data obtained in the previous years.

Discussion and conclusion

According to Leather [1908] capillarity starts from the surface, and suction pressure is developed as a result of increased curvature of water film caused by the evaporation of water from the soil

TABLE VII(a)

FIELD No. 78

Field experiment I

(Moisture as percentage on oven dry soil)

Dates (1939-40)	27·3	12·4	30·4	30·6	19·7	2·8	12·8	28·8	12·9	22·9	19·10	17·11	18·12	21·1	13·2	24·2	4·3	19·3	30·3
Rain fall (in.)	1·42	..	..	2·79	1·75	..	0·87	0·16	0·67	1·09	..	..	..	0·59	3·03	..	..	1·79	..
0-6 in.																			
Artificial mulch	11·93	5·41	3·79	9·69	15·60	6·90	8·80	5·99	5·74	8·58	4·29	4·62	4·69	8·05	18·02	14·74	11·98	15·51	11·60
Soil mulch	8·84	3·99	3·72	6·66	13·25	5·42	7·44	5·47	4·99	5·81	3·52	4·02	4·46	7·82	13·09	9·15	8·02	9·33	8·31
Observed value of P	<0·05	<0·05	>0·05	<0·05	<0·01	>0·05	<0·05	>0·05	..	<0·08	<0·01	>0·05	..	>0·05	<0·01	<0·01	<0·01	<0·01	<0·01
S. E. per cent mean	0·8	7·1	7·5	7·5	5·4	8·0	3·6	2·4	..	3·0	5·8	5·6	..	3·7	2·5	5·0	3·0	5·4	3·7
6-12 in.																			
Artificial mulch	11·37	8·96	7·22	10·71	14·60	9·18	10·42	8·32	8·25	10·02	6·91	7·15	7·40	7·37	16·64	14·49	13·24	14·68	12·69
Soil mulch	9·99	6·85	6·23	8·80	12·07	8·37	9·71	7·98	7·64	8·58	4·63	7·23	7·51	7·15	13·60	12·06	11·12	12·18	10·65
Observed value of P	..	..	>0·05	<0·05	..	..	>0·05	..	..	..	<0·05	..	..	..	..	..	..	..	<0·05
S. E. per cent mean	..	..	6·3	0·6	..	..	4·5	..	..	..	9·8	..	..	..	..	..	..	..	5·8
2nd ft.																			
Artificial mulch	11·51	10·70	9·82	10·81	13·26	11·49	11·15	10·19	10·05	9·71	9·54	9·87	9·78	9·78	15·51	13·41	13·95	15·08	14·09
Soil mulch	10·51	9·14	8·65	7·96	9·93	10·25	9·94	9·39	9·74	9·09	8·37	9·62	9·80	9·38	13·29	13·40	12·32	13·13	12·17
Observed value of P	..	..	..	<0·05	..	..	<0·05	..	..	..	<0·05	..	..	..	..	..	..	..	>0·05
S. E. per cent mean	..	..	..	9·5	..	..	2·5	..	..	..	4·7	..	..	..	..	..	..	..	5·3
3rd ft.																			
Artificial mulch	12·18	11·91	11·74	11·65	12·74	12·34	12·21	11·53	..	10·72	10·10	11·65	11·98	11·59	14·65	14·57	14·22	15·29	14·10
Soil mulch	11·74	11·31	10·88	10·71	10·79	11·12	11·17	10·61	..	10·38	10·57	11·28	11·09	11·35	12·43	13·07	12·28	12·68	12·35
Observed value of P	..	..	..	<0·05	..	..	>0·05	..	..	..	>0·05	..	..	..	..	..	..	..	>0·05
S. E. per cent mean	..	..	..	3·9	..	..	3·8	..	..	..	2·1	..	..	..	..	..	..	..	7·7

TABLE VII (b)

FIELD No. 92

Field experiment I

(Soil moisture as percentage on oven dry soil)

Dates (1939-40)	27·3	12·4	30·4	30·6	19·7	2·8	12·8	28·8	12·9	22·9	19·10	17·11	18·12	18·1	21·1	13·2	24·2	4·3	19·3	30·3
0-6 in.																				
Artificial mulch	11·39	7·63	3·61	7·27	19·16	10·20	11·50	7·18	8·36	11·52	7·01	6·37	6·57	6·33	11·96	20·83	17·21	13·87	18·64	15·04
Soil mulch	10·72	7·62	4·65	5·63	16·84	6·49	9·53	5·54	7·08	9·98	4·38	4·99	5·79	5·28	10·61	18·88	14,19	10·95	15·54	13·05
Observed value of P	>0·05	..	..	>0·05	<0·05	<0·01	>0·05	>0·05	>0·05	<0·01	<0·01	>0·05	>0·05	>0·05	>0·05	<0·01	<0·05	>0·05	<0·05	<0·05
S. E. per cent mean	4·0	..	..	4·1	2·5	7·4	9·5	12·1	5·6	0·8	6·9	11·2	9·1	14·8	5·3	0·9	4·3	11·2	4·4	3·2
6-12 in.																				
Artificial mulch	11·88	9·75	7·40	7·32	16·64	11·71	12·61	10·07	9·66	13·01	9·20	8·96	9·36	8·19	8·67	20·26	17·81	15·68	19·26	17·76
Soil mulch	13·26	9·82	7·84	6·52	13·12	9·52	11·21	9·51	9·39	12·01	7·34	8·59	9·17	7·93	9·40	18·12	17·76	15·81	18·02	15·96
Observed value of P	..	..	..	>0·05	..	..	<0·05	..	..	..	>0·05	..	..	..	..	..	..	..	..	>0·05
S. E. per cent mean	..	..	..	6·3	..	..	2·9	..	..	..	9·7	..	..	..	..	..	..	..	..	2·4
2nd ft.																				
Artificial mulch	9·17	9·22	8·12	6·52	11·90	11·96	11·78	11·82	11·02	12·15	11·54	11·39	11·68	10·13	10·64	17·58	16·54	15·43	17·64	16·89
Soil mulch	11·20	10·69	8·90	6·96	10·61	10·01	10·78	10·31	10·48	11·37	9·31	11·26	10·88	10·00	10·83	14·85	16·34	14·92	16·91	15·81
Observed value of P	..	..	..	>0·05	..	..	<0·05	..	..	..	<0·05	..	..	..	..	..	..	..	..	>0·05
S. E. per cent mean	..	..	..	6·3	..	..	1·8	..	..	..	6·8	..	..	..	..	..	..	..	..	4·9
3rd. ft.																				
Artificial mulch	11·78	10·89	8·49	7·01	11·85	11·57	12·09	12·22	..	12·73	11·59	12·84	14·41	12·62	13·29	14·68	15·45	15·80	16·50	15·89
Soil mulch	13·12	11·82	8·66	8·18	12·02	11·73	11·83	11·81	..	12·25	10·64	12·31	12·26	12·15	12·53	12·72	13·98	14·05	14·39	14·59
Observed value of P	..	..	..	>0·05	..	..	>0·05	..	..	..	>0·05	..	..	..	..	..	..	..	..	<0·05
S. E. per cent mean	..	..	..	8·4	..	..	3·1	..	..	..	5·4	..	..	..	..	..	..	..	..	1·7

TABLE VIII

Field experiment II

(Moisture as percentage on oven dry soil)

Dates	14/2/41	18/5/41	16/6/41	13/8/41	18/9/41	8/11/41
			0-6 in.			
Rain fall	0·82	2·26	2·51	5·36	3·02	nil
Artificial mulch	14·79	13·24	13·79	17·42	13·96	3·85
Soil mulch	10·56	8·23	7·61	15·11	10·85	4·71
Observed value of P	<0·01	<0·01	..	<0·01	<0·01	<0·05
S. E. per cent mean	1·3	5·1	..	4·0	3·7	14·9
			6-12 in.			
Artificial mulch	13·21	11·36	13·75	15·16	14·17	7·81
Soil mulch	10·96	8·71	11·11	12·83	12·51	8·61
Observed value of P	<0·05	..	..	..	<0·05	..
S. E. per cent mean	3·8	..	..	..	3·2	..
			2nd ft.			
Artificial mulch	8·94	9·16	12·56	13·86	14·65	11·22
Soil mulch	7·98	7·64	9·90	11·89	13·26	11·22
Observed value of P	>0·05	..	..	..	<0·01	..
S. E. per cent mean	10·0	..	..	..	2·2	..
			3rd ft.			
Artificial mulch	7·59	7·91	8·86	10·04	13·86	12·27
Soil mulch	8·14	7·74	8·26	9·34	11·33	11·28
Observed value of P	>0·05	..	..	..	<0·01	<0·05
S. E. per cent mean	5·1	..	..	..	5·1	2·4

surface. This pressure decreases with the depth. Consequently water can rise to the surface only from a limited depth. The effect of mulches will therefore be limited to the depth from which water can rise, and will be more effective in the surface layer than in the lower layers. The results of experiments conducted by us support the conclusions drawn by Leather and further supported by the work of Sen [1930] and Carbery and Chakladar [1936]. Differences in the moisture content of soil mulched and artificial mulched plots on different dates are given in Table IX.

TABLE IX

(Moisture as percentage on oven dry soil)

Dates	0-3 in.	3-6 in.	6-12 in.	2nd ft.	3rd ft.
24 February 1940	7·06	5·59	2·48	0·01	1·57
4 March 1940	4·83	3·96	2·12	1·63	1·94
30 March 1940	5·94	3·29	2·04	1·92	1·75

These data clearly show that due to mulching there can be more moisture in the upper layers than in the lower layers, and conservation effect of mulch starts from the surface.

The results of pot and field experiments show that soil under artificial mulch can absorb more water than under soil mulch, as the water which passes through a layer of artificial mulch is protected from direct heat of the sun and the desiccating influence of the wind. Soil temperatures under artificial mulch are always lower than those under soil mulch or unstirred plots (Fig. 1). Therefore, after the rains the moisture under artificial mulch is always higher. During winter when conditions are less dry there is more absorption of water than in summer when comparatively dry conditions prevail.

When rains stop, there is intense evaporation due to increase in atmospheric temperatures, fall in relative humidity, and higher status of moisture in soil. During this period soil is too wet,

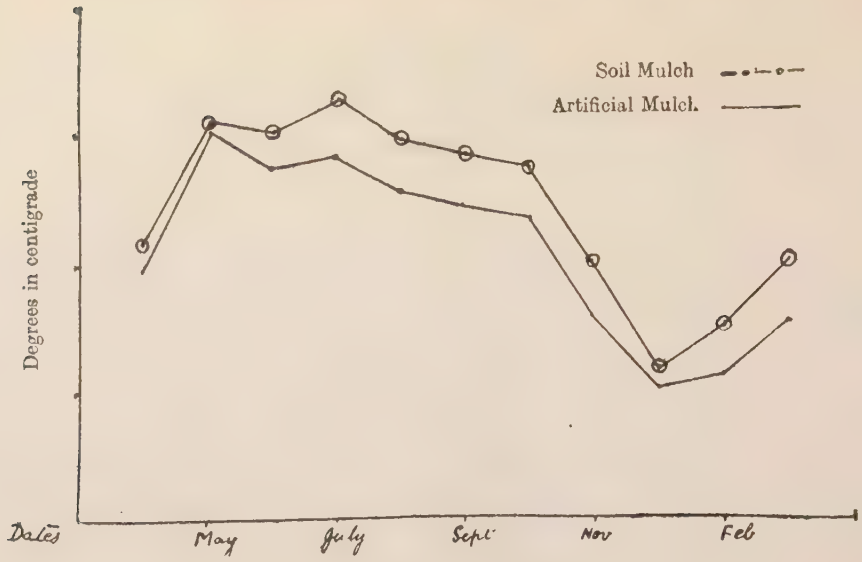

FIG. 1. Soil temperatures

and cannot be cultivated to form a mulch. Till it attains that condition (3-6 days period), 39·5 to 46·3 per cent of the total moisture present is lost. During the same period the losses from the artificial mulch are 10·4 to 27·2 per cent. After the formation of soil mulch, losses become more from the soil under artificial mulch (Figs. 2 and 3). It is only due to the initial start which soil under artificial mulch acquires that there remains over a certain period more moisture under artificial mulch, otherwise soil mulch is more effective in conservation of moisture. It is therefore not

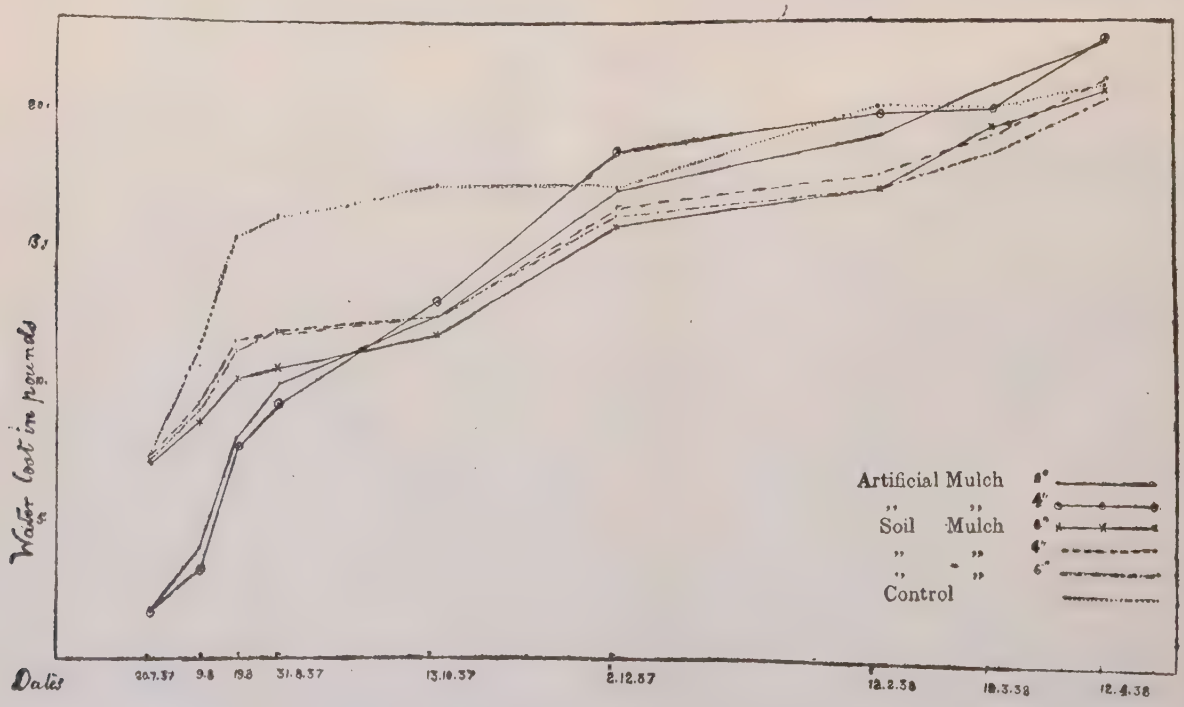

FIG. 2. Total loss of water from 20 July 1937

correct as maintained by workers like Harris and Jones [1918] that artificial mulches are more effective than soil mulch in the conservation of moisture. The obvious conclusion is that artificial mulch protects the soil from the heat of the sun, while soil mulch, in addition to it, also breaks the capillary connections and this slows down the upward movement of moisture.

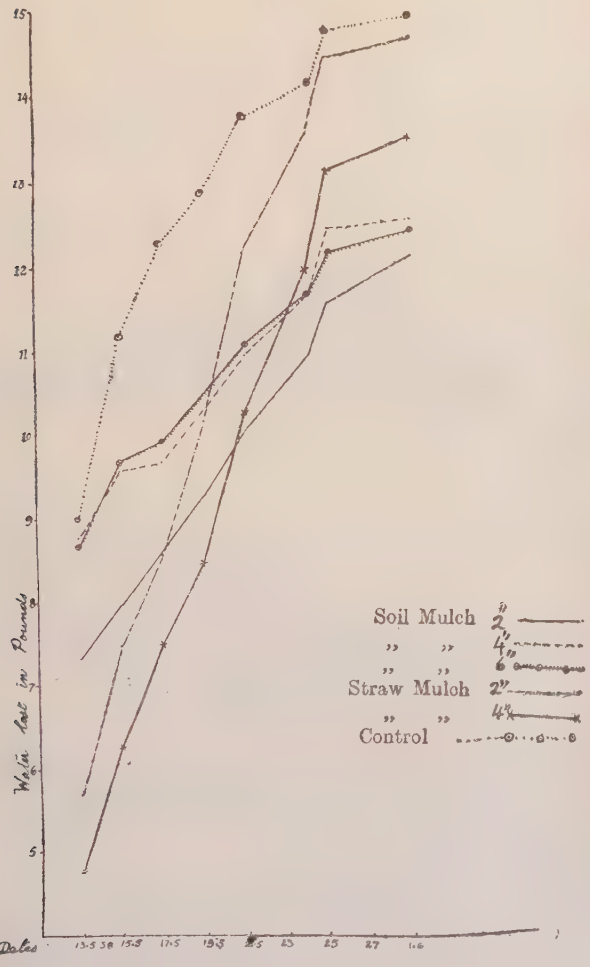

Fig. 3. Total amount of water from 13 May 1938

It is only for a certain period after the application of water that a soil under artificial mulch contains more moisture, and this period depends on the meteorological conditions. During summer when dry conditions prevail this period lasts from 20 to 30 days, that there is a significant difference. During winter when the temperatures are low and less dry conditions exist, differences are more, and remain for a longer period. From 19 July to 2 August in a period of 14 days there was a decrease of 8·70 and 7·83 per cent, and from 13 February to 4 March in a period of 19 days there was fall of 6·04 and 5·07 per cent of moisture from plots under artificial and soil mulch respectively. Unlike the observations of Russell [1940], the artificial mulch has been observed to retain more moisture than soil mulch even during rainless periods, but this duration will depend on the meteorological conditions.

Yield of the crop

Cotton crop was sown on 2 April 1940 and barley on 11 October 1941. After sowing of the crop artificial mulch was removed. The yields in pounds per acre of both the crops are given in Table X.

Table X

	Seed cotton	*P*	Barley grain	*P*
Artificial mulch .	1423	<0·05	160	>0·05
Soil mulch .	541	119	119	..

The normal time for the sowing of cotton is the month of April or May, but under dry farming conditions cotton cannot be sown during these months for want of rains. Therefore, it is sown at the end of June or the beginning of July when the monsoons break, but then it is very late. The crop sown so late yields very low as it is left with a small growing period. It was therefore decided to ascertain whether by the application of artificial mulches the moisture conserved due to winter rains could be carried to the month of April, and cotton sown in these plots could yield well. The results show that yields of cotton obtained from the plots under artificial mulch are much higher than those under soil mulch. Under dry farming rains close by the middle of September and the moisture is to be carried for sowing of winter crops to the last week of October or beginning of November. It has been observed that the crops sown late yield well. To find out the effect of late sowing in the artificial mulched plots barley was sown on 11 November 1941. The yield results show that there were 41 lb. more barley from the artificial mulched plots. The differences are not so great as in the case of cotton, but the results are in accordance with the moisture data reported. At the time of sowing cotton there was 2·11 per cent more moisture in a 3 ft.

column under artificial mulch than soil mulch. While at the time of sowing barley on 11 November 1941 there was no significant difference of moisture in the surface 2 ft. but in the third foot there was about 1 per cent more moisture in the plots under artificial mulch. It is probably due to this deep-seated moisture that slight increase in yields of barley was obtained from the artificial mulched plots.

As already reported, during summer it is only for a period of 25 to 30 days that there is more moisture in the artificial mulched plots. Therefore *rabi* crops (winter crops) in the plots under artificial mulch can only derive benefit if sown a month after the close of rains. In case the interval is longer the differences will be slight, and this will not lead to any advantage. However, in the winter season a crop can be sown with advantage a month or two after the close of winter rains.

Economic possibilities of artificial mulches

It may however be pointed out that the economic possibilities of artificial mulches have not been fully explored, as they are governed by many considerations of which the availability of waste plant material is an important factor. In the experiment reported cotton sticks were employed as artificial mulch, but it should be left to the expediency of zemindars to utilize whatever waste plant material is available to them in a particular locality. Cotton sticks are ordinarily used by the zemindars for fuel purposes, but the same use can be made even after they have secured the purpose of artificial mulch. The cost of spreading and removing should be quite nominal as the zemindar under dry farming conditions is not very busy and is not required to employ extra labour. However, for purposes of working out economics, the cost of spreading and removing may be reckoned at Rs. 7*. There may be slight loss of the material itself which may amount to Rs. 5. Income due to increase in yield of 882 lb. of seed cotton amounts to Rs. 53 resulting in net profit of Rs. 41.

(On prewar basis)

	Rs.	A.
* Cost of carting 200 md. of cotton sticks required to cover one acre (wages of two labourers and rent of two carts)	5	0
Wages of two labourers for spreading of cotton sticks	1	0
Wages of two labourers for removing of cotton sticks	1	0
Price of 25 md. of cotton sticks lost during use @ -/3/- per md.	4	11
Total expenditure	11	11
Income due to 10 md. 31 sr. (882 lb.) of seed cotton at Rs. 5 per md.	53	9
Net profit	41	14

The use of artificial mulches has been made for growing sugarcane under dry farming conditions by spreading the cane trash in between the rows. The extra moisture thus conserved, enables the sugarcane crop to withstand drought in years of scanty or unevenly distributed rainfall.

Summary and conclusions

The results of a study of the relative effect of artificial and soil mulches on the conservation of soil moisture has been presented.

1. There is more moisture under artificial mulch than soil mulch over a period of 20 to 60 days depending upon the seasonal conditions.

2. Soil mulch conserves moisture better than artificial mulch, but greater moisture under artificial mulch is due to the fact that 39 to 46 per cent of the moisture from the soil is lost before it can be cultivated to form soil mulch. After a soil mulch is formed losses from the soil mulched plots are less than from the artificial mulch plots.

3. There is more absorption of water in artificial mulch plots. When rain falls in small showers it does not increase the moisture of heavy type of soil.

4. Artificial mulch is more effective on a heavy type than on light type.

5. Effect of meteorological factors on the evaporation has been discussed. Artificial mulches are less effective during summer than during winter months.

6. Artificial mulch 2 in. deep and soil mulch 4 in. deep bring about maximum conservation of moisture.

7. Yields of cotton and barley from the artificial and soil mulch plots are given and the possibility of growing crops in the moisture conserved by artificial mulches has been discussed.

Acknowledgement

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A SIMPLE METHOD FOR ESTIMATING CARBONATES IN SOILS

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Several methods for the estimation of carbonates in soils have been proposed from time to time. Soil workers are familiar with the methods of Brown and Escombe [1900], Hall and Russell [1902], Amos [1905], Collins [1906], Marr [1908], Gaither [1912], Shrewsbury [1912], MacIntyre and Willis [1913 ; 1915], Hutchinson and MacLennan [1914], Truog [1916], Hardy [1921], Sanyal [1923], Underwood [1926], Clark and Collins [1929], Schollenberger [1930], and Puri [1930].

All the above methods require elaborate glass apparatus and involve complicated manipulations. They are, therefore, unsuitable for use in ordinary routine analysis, where a large number of estimations have to be made in a day. Hence there is a real need for a simple, rapid and fairly accurate method.

Puri [1930], working in these laboratories, developed a direct titrametric method. It offers no doubt certain advantages in point of simplicity and rapidity. It consists in titrating with $N/2$ H_2SO_4 a known weight of soil suspended in a saturated solution of $CaSO_4$ in the presence of 10 c.c. of $N/10$ Al_2Cl_6 solution and an equal amount of brom thymol blue and brom cresol green indicators with boiling after each addition of acid till the colour of the supernatant liquid is golden yellow. In several instances the results however differ considerably from those obtained by the gravimetric method.

This has been tested and found to give lower results than the gravimetric method. This is partly attributed to the acidity of 10 c.c. of $N/10$ Al_2Cl_6 solution equivalent to 2 c.c. of $N/2$ H_2SO_4 not being taken into account by Puri and partly to the fact that the amount of acid used is not enough to completely decompose the soil carbonates.

The gravimetric method employed in this laboratory for comparative tests consists in boiling the soil with about 50 c.c. of normal HCl (1 : 10) at atmospheric pressure for 5 min. The CO_2 evolved is first led through a condenser which retains back the HCl fumes, then dried by passing through U-tubes containing strong H_2SO_4 soaked in pumice and next collected in soda lime U-tubes. After the boiling is over, about a litre of CO_2-free air is aspirated for half an hour to sweep away all the evolved CO_2 from the reaction flask. There are guard tubes containing H_2SO_4 soaked in pumice attached to the further end of the soda lime tubes to retain any moisture that may enter the apparatus by back suction. This method has been found to yield satisfactory results with most Indian soils which are usually poor in organic matter.

TABLE I

Comparison of values for CO_2 by gravimetric and Puri's titrametric methods

Serial No.	Locality of soil samples	Per cent CO_2		
		Gravimetric method	Puri method	Difference
1	Nagpur, Central Provinces	0·82	0·30	—0·52
2	Dholkapaldi, Bombay (Good)	0·89	0·22	—0·67
3	Dholkapaldi, Bombay (Bad)	2·86	2·15	—0·71
4	Delhi, Depth 13—14 ft.	2·69	1·56	—1·13
5	Delhi, Depth 4 ft. 4 in.—6 ft. 4 in.	6·65	5·42	—1·23
6	Bannu, N.-W.F. Province	6·47	5·60	—0·87
7	Pusa, Bihar . . .	15·78	14·53	—1·25
8	Akola, Central Provinces	3·21	2·33	—0·88
9	Coimbatore, Madras .	1·15	0·62	—0·53

From Table I it is evident that the CO_2 values by the Puri method are considerably lower than those obtained by the gravimetric method. If an allowance is made for the acidity of the 10 c.c. of $N/10$ Al_2Cl_6 solution used in the Puri method, the CO_2 values become higher by about 0·44 per cent in every case, but are still lower than the CO_2 values by the gravimetric method. This is due to the amount of acid used being not enough to completely decompose the soil carbonates. A slight excess of acid is essential to completely decompose the soil carbonates, as will be shown in the sequel. If the calculations were made as $CaCO_3$, the differences between the values by the two methods would be about $2\frac{1}{2}$ times higher than those given above.

Detailed account of the proposed method. Depending on the approximate amount of carbonates present in a soil as judged qualitatively by the strength of effervescence on decomposing a little of the soil with dilute acid, two 1 to 10 gm. portions of the soil sample are exactly weighed out in two 500 c.c. conical flasks, to each of which are added 50 c.c. of distilled water and a measured quantity of half normal hydrochloric acid in slight excess (about 4 to 5 c.c.) of what is actually required to completely decompose the soil carbonates.

The contents of one of these flasks are then slowly boiled for 5 min. on wire-gauze over a small flame. The excess acid is finally titrated back with deci-normal caustic soda using phenolphthalein as indicator.

The contents of the second flask are shaken from time to time for half an hour in the cold at room temperature, and then the excess acid is titrated back as in the first case.

The titre figures are quite reproducible and the end-point is very sharp. The alkali used is converted into half-normal strength by dividing the titre figure by five. The quotient thus obtained is subtracted from the c.c.s of $N/2$ HCl taken and the resultant figure gives the amount of acid consumed to decompose the soil carbonates present in the sample taken for analysis. One c.c. of $N/2$ HCl corresponds to 0·011 gm. CO_2 or 0·025 gm. $CaCO_3$. The values for CO_2 obtained by either boiling or shaking in the cold are fairly concordant, and, therefore, the mean of these two values has been taken for comparing with the CO_2 values obtained by the gravimetric method.

The effect of time of boiling, or shaking in the cold at room temperature on the reaction between acid and soil carbonates is seen from the following results. Two grams of a Delhi soil having 6·65 per cent of CO_2 were treated with 50 c.c. of water and 17 c.c. of $N/2$ HCl which included about 5 c.c. of $N/2$ HCl in excess of what is actually required to completely decompose the soil carbonates.

TABLE II

Effect of time of shaking in the cold or boiling on the reaction between acid and soil carbonates

Minutes shaken	Per cent CO_2	Minutes boiled	Per cent CO_2
5	5·91	1	6·44
10	6·05	2	6·40
15	6·24	3	6·55
20	6·30	4	6·56
25	6·38	5	6·66
30	6·63	7	6·62
45	6·69	10	6·66
60	6·73	15	6·62

It is evident that either shaking at room temperature for 30 min. or boiling for 5 min. in the presence of slight excess of acid gives the most satisfactory values for CO_2 comparable with that given by the gravimetric method. It is necessary that a definite excess of acid should

be maintained to completely decompose the soil carbonates under the conditions of the experiment. This excess of $N/2$ HCl is diluted in the presence of 50 c.c. of water to about $N/25$ strength which is too dilute to have any appreciable action on the organic matter or soil bases. This will be evident from the data given in Tables III and IV.

A number of typical soils from different parts of India have been examined by the new method and the results compared with those by the gravimetric method in Table III.

TABLE III

Comparison of the values for CO_2 by N/2 HCl method and the gravimetric method

Serial No.	Locality of soils	Characteristics	Per cent CO_2			
			$N/2$ HCl method			Gravimetric method
			Boiled 5 min.	Shaken 30 min.	Mean	
1	Delhi	Alluvium depth 5–6 ft.	6·21	6·46	6·34	6·51
2	,,	,, ,, 4 ft. 4 in.–6 ft. 4 in.	6·54	6·62	6·58	6·65
3	,,	,, ,, 14–15 ft.	2·59	2·64	2·62	2·69
4	,,	,, ,, 0–1 ft.	0·04	0·04	0·04	0·01
5	,,	,, ,, 1–2 ft.	0·04	0·06	0·05	0·04
6	,,	,, ,, 2–3 ft.	0·04	0·04	0·04	nil
7	,,	,, ,, 3–4 ft.	0·03	0·05	0·04	0·05
		North-west Frontier Province				
8	Bannu	Alluvium depth	6·43	6·48	6·46	6·47
9	Taru Jabba	,, ,,	7·58	7·69	7·64	6·61
10	Peshawar	,, Wheat Land	7·03	6·81	6·92	7·00
11	,,	,, Grass ,,	6·87	6·81	6·84	6·86
12	,,	,, Kallar (alkali) effluorescence	6·05	6·05	6·05	6·25
		Sind				
13	Sukkur	Good alkali soil	5·59	5·33	5·46	5·47
14	,,	Bad ,, ,,	5·03	4·78	4·91	4·76
		Bombay				
15	Poona	Daccan trap	2·80	2·80	2·80	2·77
16	Dholkapaldi	Alluvium good soil	0·86	0·88	0·87	0·89
17	,,	,, bad ,,	2·69	2·69	2·69	2·80
18	Dharmuj	Alluvium	0·66	0·68	0·67	0·69
19	Nadiad	,,	0·79	0·86	0·80	0·76
		Central Provinces				
20	Nagpur	Black soil	0·77	0·79	0·78	0·82
21	Akola	Black cotton soil	2·91	3·13	3·02	3·14
		Panjab				
22	Lyallpur	Alluvium	0·66	0·66	0·66	0·66
23	Gujranwalla	,,	0·40	0·42	0·41	0·41
24	Solon	Hill soil	1·14	0·92	1·03	1·04
25	Simla	,, ,,	nil	nil	nil	nil

TABLE III—*contd*

Serial No.	Locality of soils	Characteristics	Per cent CO_2			
			N/2 HCl method			Gravimetric method
			Boiled 5 min.	Shaken 30 min.	Mean	
		United Provinces				
26	Saharanpur	Alluvium	nil	nil	nil	nil
27	Cawnpore	„	0·22	0·18	0·20	0·19
		Bihar				
28	Pusa	Alluvium calcareous	15·40	15·40	15·40	15·78
29	Sepaya	„ „ 12-18 in.	3·36	3·30	3·33	3·33
30	Gaya	Alluvium	1·76	1·76	1·76	1·70
31	Ranchi	Laterite acid	nil	nil	nil	0.04
32	Banka	„ „	nil	nil	nil	nil
		Orissa				
33	Cuttack	Laterite acid	nil	nil	nil	nil
34	Balasore	„ „	nil	nil	nil	nil
		Bengal				
35	Dacca	Laterite acid $pH = 3.92$	nil	nil	nil	0·04
36	Darjeeling	Acid. Tea soil	nil	nil	nil	0·06
		Assam				
37	Karimganj	Acid $pH = 5·0$	nil	nil	nil	0·05
38	Jorhat	„ $pH = 4·6$	nil	nil	nil	0·04
		Burma				
39	Mandalay	Acid $pH = 4·0$	nil	nil	nil	0·04
		Madras				
40	Coimbatore	Brown soil	1·10	1·13	1·12	1·15
41	Bangalore	Red soil	0·04	0·06	0·05	0·06
42	Guntur	Black soil	1·05	1·05	1·05	1·05
43	Coorg	Acid organic soil $pH = 5·0$, 15 per cent loss on ignition	nil	nil	nil	0·40
44	Coorg	Acid organic soil $pH = 5·0$, 9 per cent loss on ignition	nil	nil	nil	0·87
45	Coorg	Acid organic soil $pH = 5·0$, 8 per cent loss on ignition	nil	nil	nil	0·30

It is seen that the new method is applicable to all the Indian soils tried and gives results closely agreeing with those obtained by the gravimetric method except in the case of the few Coorg soils which are rather rich in organic matter. The latter soils are acid having a pH of 5·0 and are therefore not expected to contain any native carbonate as indicated by the gravimetric method. They as well as the other acid soils examined give off no CO_2 by the new method, which thus gives a true picture of the carbonate status of soils in general.

The effect of such substances as salts, oxides and silicates on the results by the new method is hardly appreciable as can be seen from the results in Table IV. To two-gram portions of a soil was introduced 0·2 to 0·3 gm. of different oxides, salts, and silicates which amounted to

10 to 15 per cent of the soil taken. With 50 c.c. of water and 16 c.c. of $N/2$ HCl which included 4 c.c. of $N/2$ HCl in excess, the contents were boiled for 5 min., after which the excess acid was determined as usual.

TABLE IV

Effect of different oxides, salts, and silicates on the N/2 HCl method for estimating soil carbonates

Serial No.	Impurities added	Per cent CO_2 found	Difference from control
1	Control. Soil alone	6·47	—
2	Sodium chloride	6·51	+0·04
3	,, nitrate	6·47	nil
4	,, sulphate	6·43	—0·04
5	Potassium chloride	6·55	+0·08
6	Calcium chloride	6·56	+0·09
7	Magnesium chloride	6·47	nil
8	10 c.c. N/10 aluminium chloride*	6·43	—0·04
9	Aluminium oxide**	6·46	—0·01
10	Ferric Oxide	6·55	+0·08
11	Titanium oxide	6·40	—0·07
12	Manganese dioxide	6·46	—0·01
13	Silica**	6·47	nil
14	Talc	6·54	+0·07
15	Kaolin	6·55	+0·08
16	Fuller's Earth	6·55	+0·08

* The acidity of aluminium chloride solution used was equivalent to 2 c.c. of $N/2$ HCl for which due allowance was made.

** Alumina and silica were alkaline requiring respectively 0·4 c.c. and 0·2 c.c. of $N/2$ HCl for neutralisation and due allowance was made for this.

The proposed method requires a minimum of glass apparatus which is easily available in any laboratory, and the manipulations involved in its working are very simple and can be quickly carried out. It offers advantages in point of simplicity and rapidity over the other methods. The simplicity and the degree of accuracy mark out the method as being most useful to soil workers, especially those engaged in soil survey work.

SUMMARY AND CONCLUSIONS

A simple and rapid method for estimating carbonates in soil has been outlined. It consists in either boiling for 5 min. or agitating at intervals for half an hour at room temperature a known weight of a soil with a measured quantity of $N/2$ HCl in slight excess (4 to 5 c.c.) of what is actually required to completely decompose the soil carbonates and 50 c.c. of water in a 500 c.c. conical flask and then titrating back the excess acid with decinormal caustic soda using phenolphthalein as indicator. The end-point is sharp and the titre figures are reproducible.

The method has been tested with a variety of soil types available in India and has proved to be of sufficient accuracy to warrant its employment in routine soil analysis, or on the field where a large number of samples have to be quickly tested.

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ERRATA

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Page 49, line 22 (1st col.), *for* 'USTILAGO ANDROPOGONIS-FINITIM' *read* 'USTILAGO ANDROPOGONIS-FINITIMI'

Page 50, line 11 from bottom (1st col.), *for* 'CINTRACTIA DISVANS' *read* 'CINTRACTIA DISTANS'

Page 52, line 10 from bottom (2nd col.), *for* 'of smuts hitherto unrecorded for India' *read* 'of smuts, of which 17 were hitherto unrecorded for India'

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